

**SHIPHANDLING SIMULATION BASED EVALUATION
OF PROPOSED CHANNEL IMPROVEMENTS
IN BOSTON HARBOR**

DTMA 91-88-C-80024
Task Order 4

FINAL REPORT

Prepared for:



Department of the Army
New England Division, Corps of Engineers
424 Trapelo Road
Waltham, Massachusetts 02254-9149

Prepared by:

Computer Aided Operations Research Facility
National Maritime Research Center
U.S. Merchant Marine Academy
Kings Point, New York 11024

MarineSafety
international

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Section 1 INTRODUCTION AND SUMMARY

This Final Report describes the background, methodology and findings of a shiphandling simulation based evaluation of proposed channel improvements in Boston Harbor. The study was performed for the United States Army Corps of Engineers, New England Division (NED) and co-sponsored by the Massachusetts Port Authority (MASSPORT). MarineSafety International (MSI) performed the study via a Task Order Contract with the U. S. Maritime Administration (MARAD), DTMA 91-88-C-80024, Task Order 4. The Final Report is the concluding deliverable defined in the scope of work entitled "Boston Harbor Navigation Improvement Project, Scope of Work - Ship Simulation Modeling." This study was activated by MARAD on October 10, 1991.

The study employed the various shiphandling simulation and analysis capabilities resident at MSI's Computer Aided Operations Research Facility (CAORF) and the Newport Simulator Training/Research Complex. Fundamental to the conduct of this study was the use of the Full Mission Bridge (FMB) simulator at the Newport facility. MSI simulators are man-in-the-loop simulators, i.e. pilots conn the simulated vessel, and all important variables such as currents, wind, bank forces, tug assistance, etc, can be included in the simulations. The simulator, therefore, provides a means of including all relevant complexities that exist in the real world in the analysis of the navigability and safety of a waterway design.

1.1 BACKGROUND

The Port of Boston is located on the western side of Massachusetts Bay approximately 50 nautical miles northwest of the tip of Cape Cod. It is the largest port in New England, covering approximately 47 square miles and is one of the United States' oldest and most historic international trading centers. The port is a source of jobs and commerce for the 13 million residents of the six-state New England region and annually handles about 25 million tons of cargo, worth more than \$7 billion. Of the tonnages handled in 1986, approximately 91 percent was liquid petroleum products, and the remaining 9 percent was non-petroleum bulk, containerized, and non-bulk cargo.

The U.S. Army Corps of Engineers has constructed and presently maintains navigation channels in Boston Harbor. Deep water access from the Atlantic Ocean is provided by three entrance channels: the Broad Sound North Channel with two lanes at depths of 35 and 40' below mean low water (MLW); the 30' deep Broad Sound South Channel; and the 27' deep Narrows Channel. The entrance channels converge in the naturally deep President Roads area where there is an anchorage of approximately 350 acres. Additional deep-draft navigation channels serve facilities based along the Main Ship Channel and three major tributaries. The Main Ship Channel extends from President Roads to the interior of the harbor and has two 600' wide lanes with depths of 35' and 40'. The three main tributary channels are the Mystic River, the Chelsea River and the Reserved Channel. The Mystic River Channel is 6,500' long and varies in width from 580' to 1,060'. The Chelsea River channel is two miles long and varies in width from 225' to 430'. The Reserved Channel is one mile long and 430' wide. All the tributary channels are maintained to a depth of 35'. Figure 1 shows the entire study area and Figures 2A, 2B and 2C show the existing channels in detail.

1.2 EXISTING PROBLEMS AND PROPOSED SOLUTIONS

Vessels that make up the world fleet continue to increase in size. However, the transportation economies of using these larger vessels cannot be fully realized for ships calling at Boston Harbor due to the restrictive channel depths and bends. The operating efficiency of large, deep-draft vessels is reduced when ships must wait for high tide (average 9.4' tidal range) to transit harbor channels or call at the port with less than a full load of cargo. There is a need to deepen channels to better accommodate the larger ships presently using the harbor and those expected in the future. Widening as well as deepening the present channels is somewhat restricted by the both the economics of the

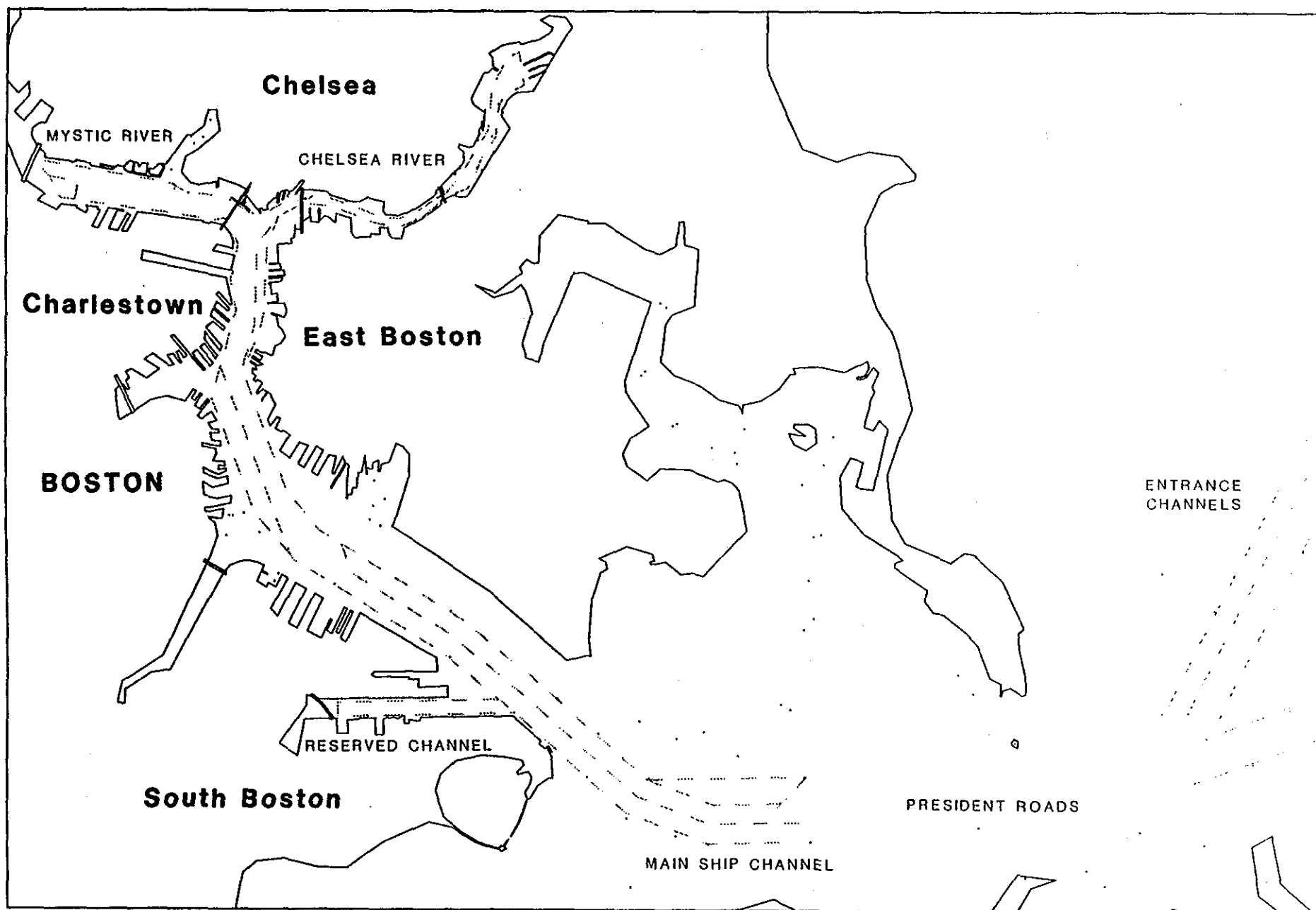


FIGURE 1 Study Area

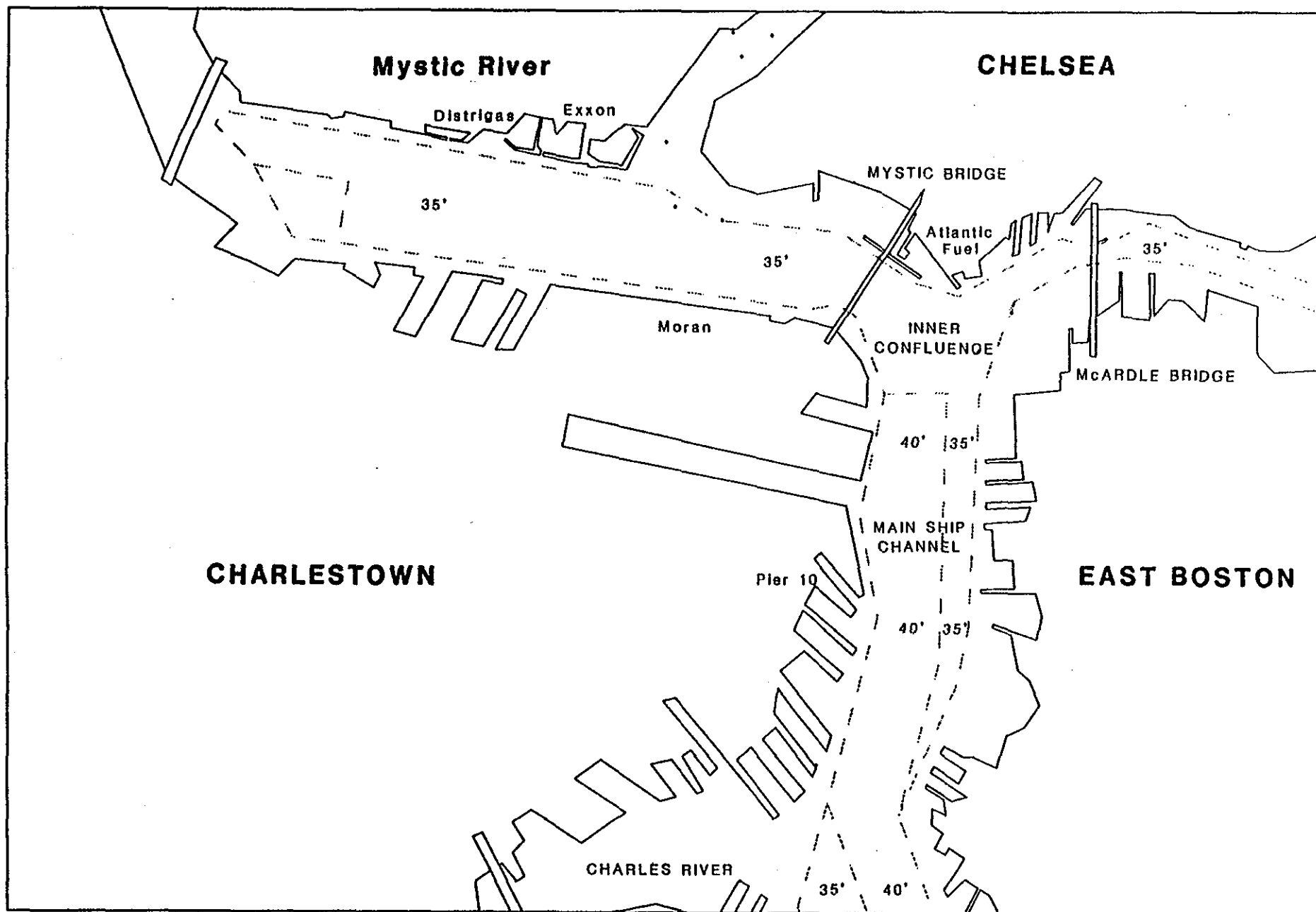


FIGURE 2A Existing Configuration - Mystic River

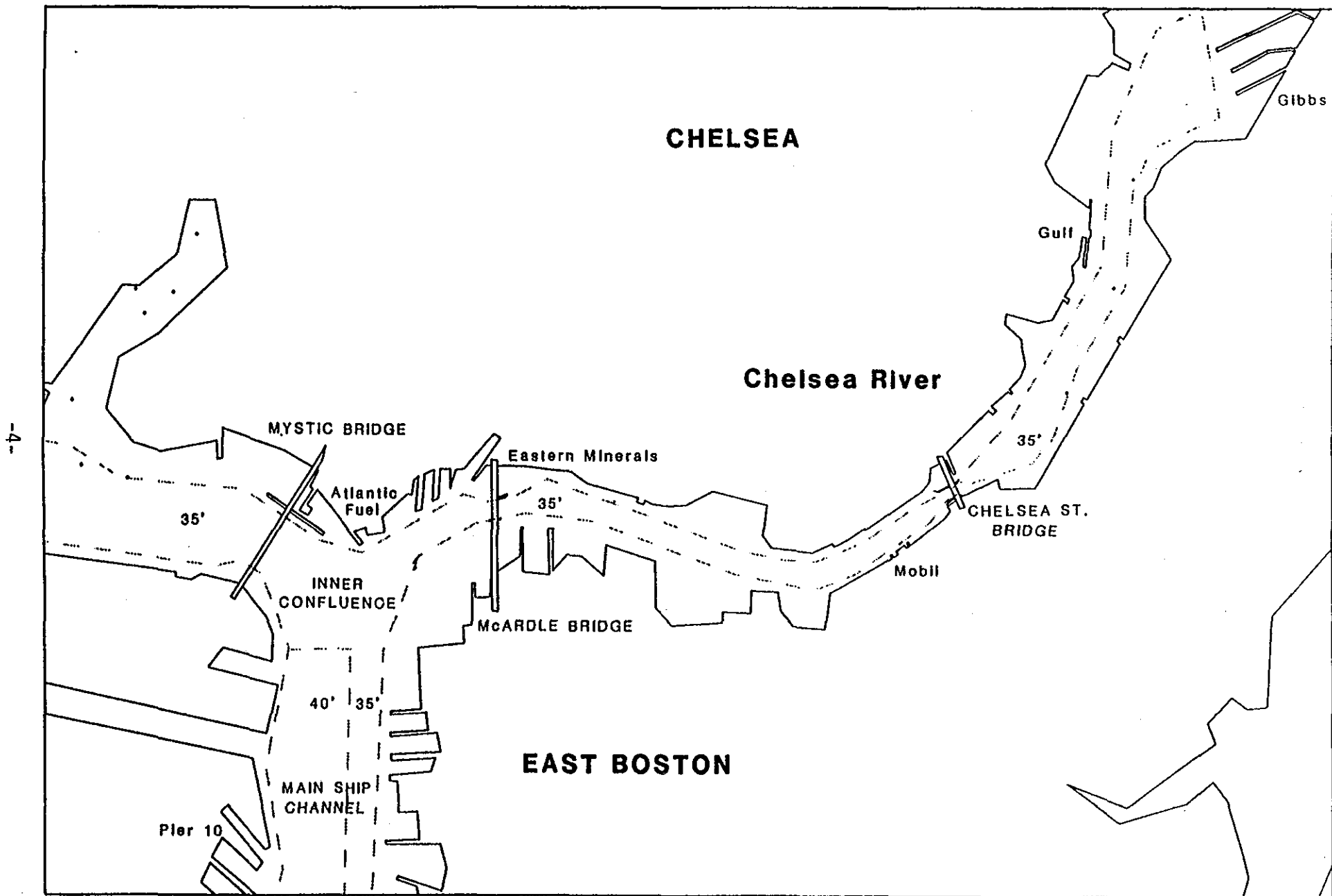


FIGURE 2B Existing Configuration - Chelsea River

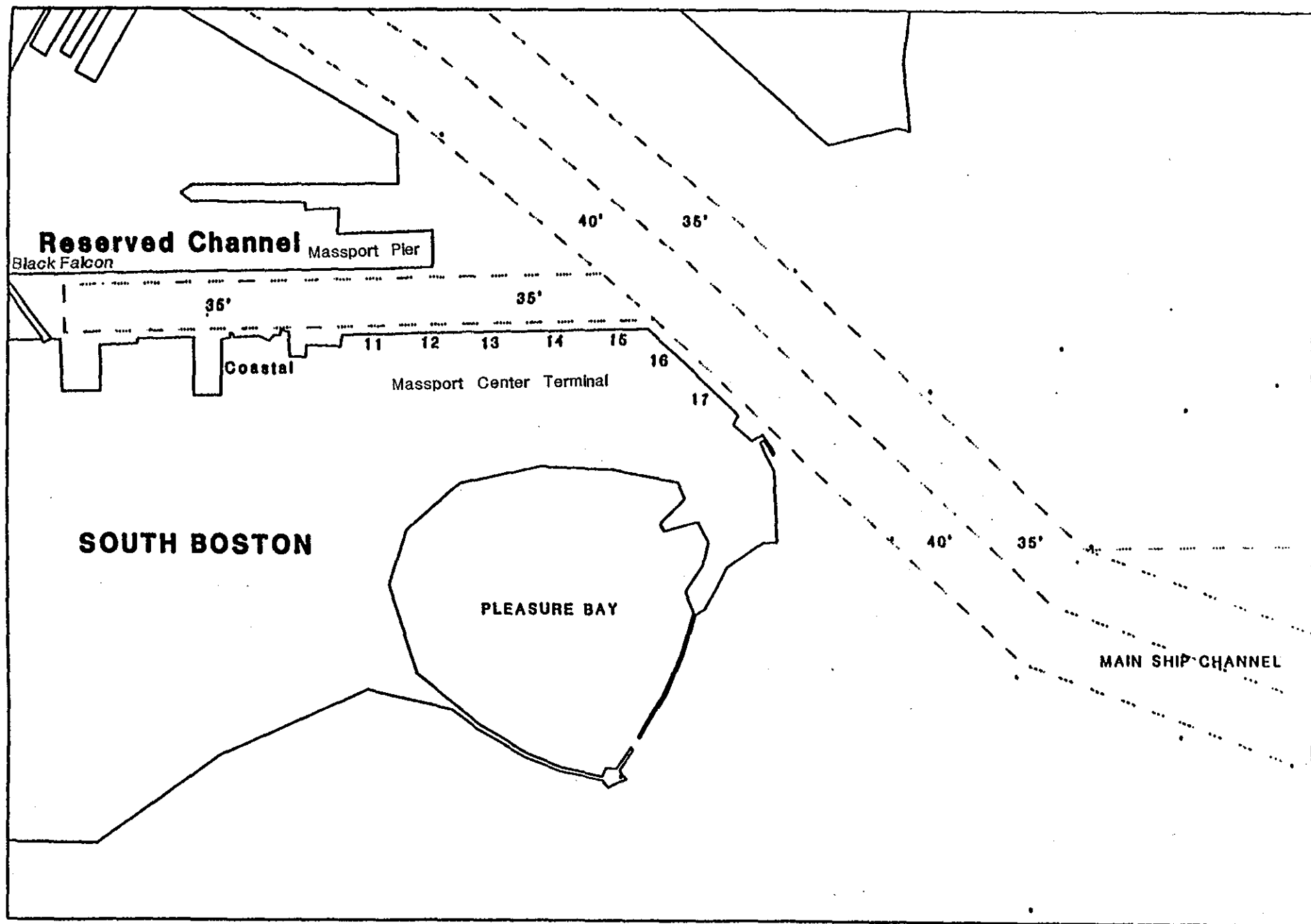


FIGURE 2C Existing Configuration - Reserved Channel

project and in some areas the stability of existing bulkheads and the need for berthing areas. In addition, portions of the main ship channel will not be deepened to 40' and maneuvering areas for deeply laden vessels will be decreased. Consequently, there are safety concerns associated with handling of more deeply laden vessels within the confines of deepened channels and maneuvering areas with the existing dimensions as well as the planned narrower channel segments and maneuvering areas.

Figures 3A, 3B and 3C show the planned project and a discussion of the approach to the analysis of the planned project follows.

1.2.1 Depth Restrictions

Although half of the Main Ship Channel has a 40' channel depth, the main restrictions to vessel navigation within the existing project are related to the limited available channel depths in the Mystic River Channel, the Chelsea River Channel, and the Reserved Channel, which are all presently maintained to 35'. Larger vessels must, therefore, load light or wait in the bay anchorage for favorable tides. This results in costly delays, decreased cargo revenues and ultimately fewer ships calling at the port. Planned improvements under simulation analysis, therefore included deepening of the tributary channels as follows: deepening the Mystic River Channel to 40' MLW; deepening the Chelsea River Channel to 38' MLW; and, deepening the Reserved Channel to 40' MLW. It is not expected that the proposed improvements will alter the size or type of vessels using the existing channels, but the improvements will allow the existing vessels to load to a deeper draft without tidal restrictions, thereby allowing the vessels to take better advantage of their cargo capacity as well as the existing 40' segments of the Main Ship Channel.

1.2.2 Safety Concerns

In addition to the restrictions imposed by the present authorized depth, there are safety concerns for deeply laden vessels: maneuvering in the Inner Confluence Area, turning from the Main Ship Channel into the Mystic River, entering the Reserved Channel and transiting the Chelsea River. The changes described below were proposed to the configuration of the channels, as well as deepening, to mitigate these safety concerns, and these changes were analyzed in this test program.

Large container and LNG vessels bound for the Mystic River must first be turned in the Inner Confluence Area. This is accomplished by extending the nose of the vessels into the Chelsea River and then backing into the Mystic River under the Mystic Tobin Bridge. Proposed modifications to the Inner Confluence Area involve widening the turning area to increase safety for vessels attempting this maneuver.

Vessels typically enter the Reserved Channel stern first. With the aid of tugs, the docking pilot turns the vessel's bow toward East Boston and backs in. Because large vessels must enter at flood tide to take advantage of the extra depth, tidal currents tend to carry the vessel farther up the Main Ship Channel. The docking pilot must compensate for this drift along with the effect of wind when attempting to back the ship into the mouth of the channel. Vessels that enter the Reserved Channel bow first must be backed out and then turned seaward upon reaching the main channel when departing. Modifications are proposed at the mouth of the Reserved Channel. They are designed to provide a safe and efficient maneuvering area for inbound and outbound vessels. This area will be maintained at 40' MLW and provides room off of the Massport Pier and a 40' MLW notch into the 35' MLW section of the Main Ship Channel. This area is shown in Figure 3C.

Another area addressed in this project is the Main Ship Channel south of the Inner Confluence Area. Large tankers entering the Mystic River typically make a wide turn, bringing them into the 35' MLW section of the Main Ship Channel. Once the Mystic River is deepened to 40', and the tankers are loaded deeper, this section of the Main Ship Channel will no longer provide an adequate depth. A

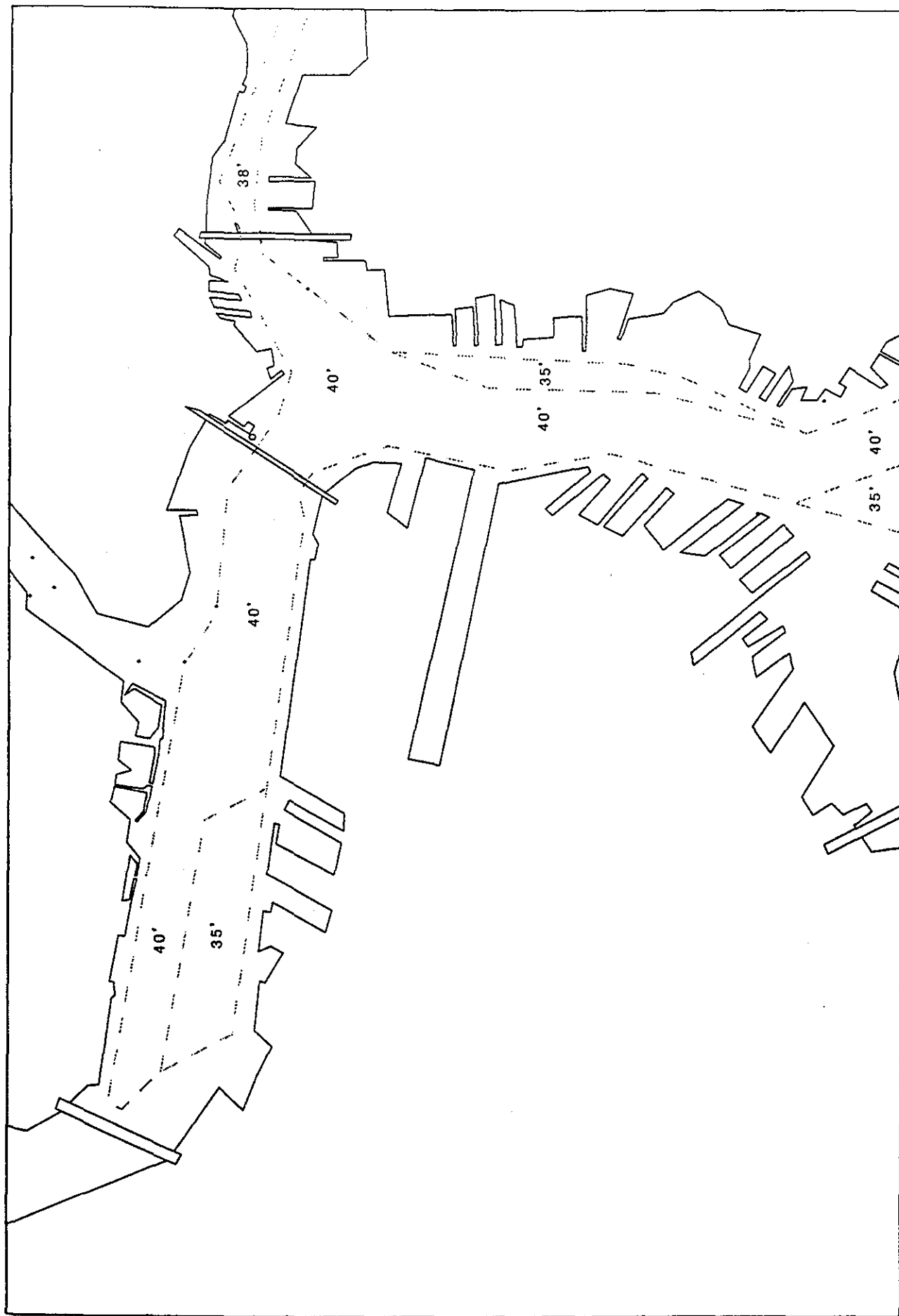


FIGURE 3A Planned Configuration - Inner Confluence Area and Mystic River

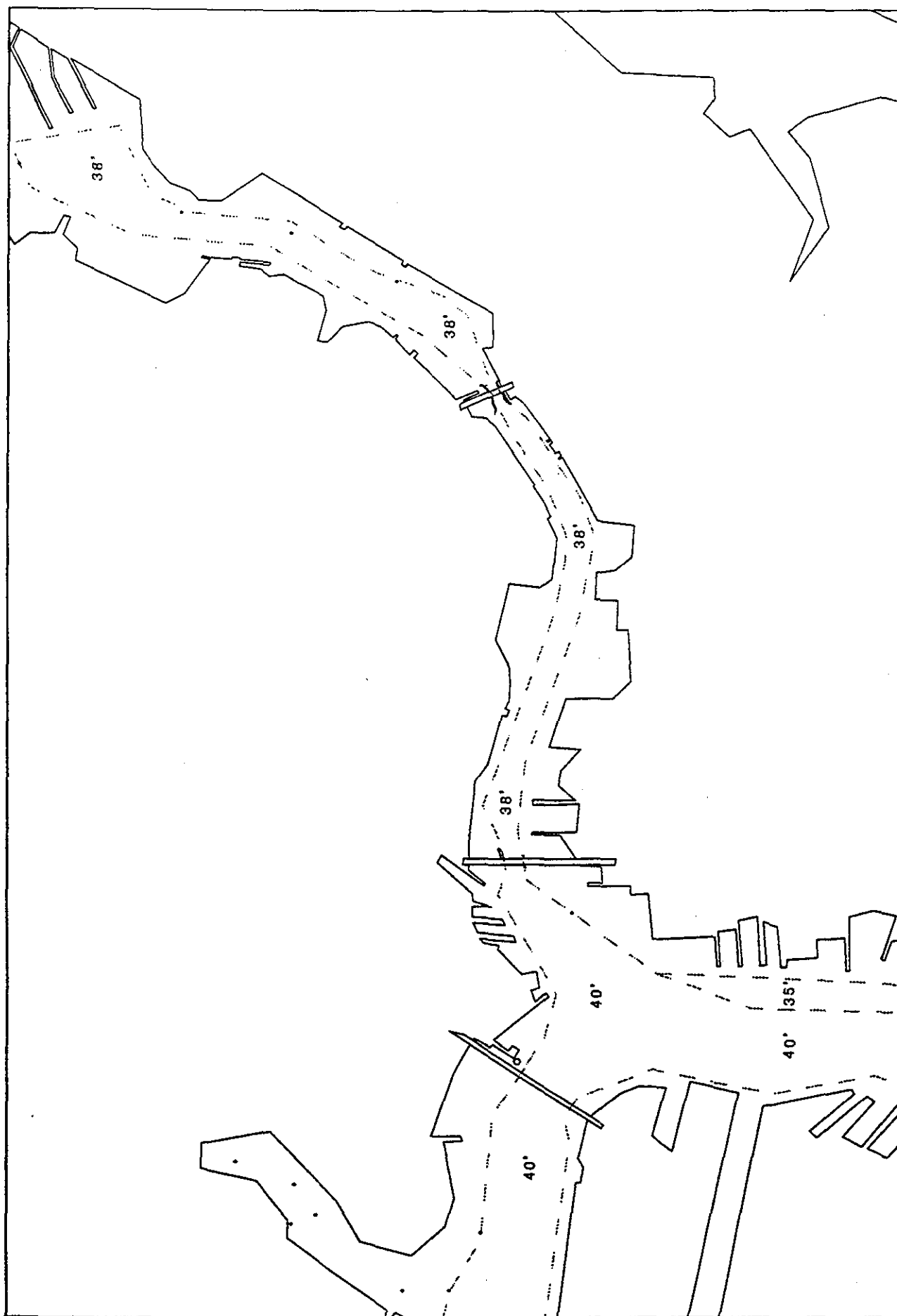


FIGURE 3B Planned Configuration - Chelsea River

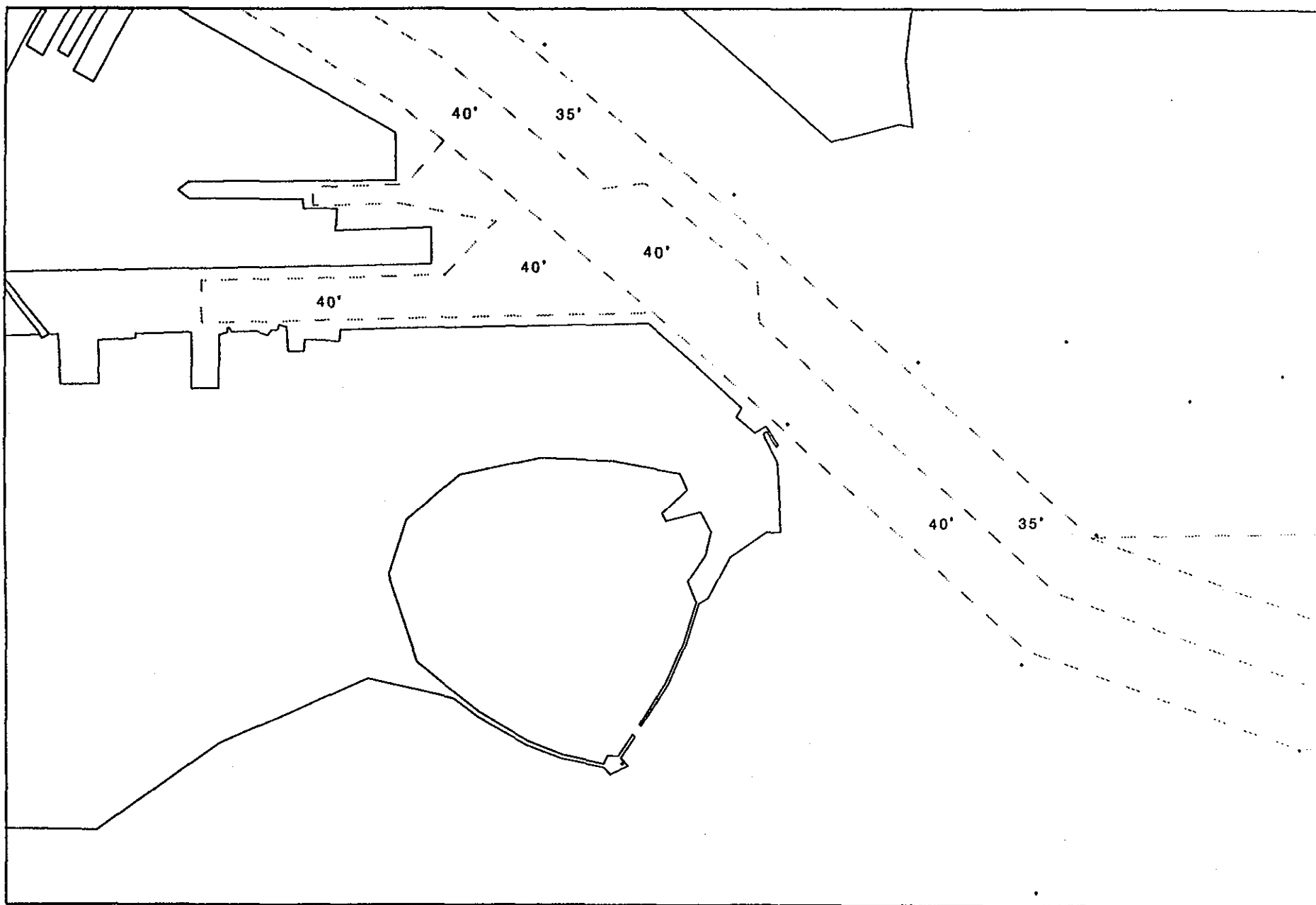


FIGURE 3C Planned Configuration - Reserved Channel

alternate design, designated as Plan 2, includes dredging the northern half of this section to 40' to allow the tankers to safely utilize this area. This is shown in Figure 4.

1.3 OVERVIEW OF STUDY METHODS

This study utilized real-time full mission simulation to analyze the safety of the proposed channel configurations. This method of analysis had the actual shiphandlers, in this case the local Docking Pilots, control the test vessels as they do in the real world. The Docking Pilots tested the channel designs under maximum credible adverse environmental conditions of wind and current. By using simulation, a waterway can be thoroughly tested before any dredging is undertaken.

The analysis of the Mystic River, the Chelsea River and the Reserved Channel was limited to two conditions, designated as "existing" and "planned". The existing channels were simulated to establish the baseline condition. The planned condition was the deepened channels including improvements in the Inner Confluence and the Reserved Channel approach.

1.4 SUMMARY OF FINDINGS

The key study findings are summarized in this section and discussed in detail in the main body of this report

1.4.1 Mystic River

All operations tested with the proposed design changes were successful in providing safe navigation in the area, and some minor modifications to the design are recommended. The results of the simulations clearly support the implementation of Plan 2 because it provides tankers a safer access to the Mystic River. There were also indications that the Inner Confluence Area may not need to be expanded, and it is recommended that more conclusive simulation tests be conducted.

1.4.2 Chelsea River

Testing indicated that vessels which currently operate in the Chelsea River, could load deeper to utilize the proposed deeper channel, provided some minor changes to the design were implemented. This would increase the amount of cargo that could be moved through this area. However, larger vessels will not gain the full benefit of the deeper channels due to the confining dimensions of the channel and horizontal clearances of the McArdle and Chelsea Street Bridges. Results showed only marginal levels of safety, using vessels with larger overall dimensions, in the planned condition.

1.4.3 Reserved Channel

The proposed design for the Reserved Channel provided safe navigation for most of the conditions tested, however, it failed to provide safe navigation under all conditions. There were strong indications that a modification to the design may be acceptable if a new maneuvering strategy (described in section 4.3.2) was employed by the pilots. This new design would require less dredging and lead to significant project savings, by possibly eliminating the requirements for the notch in the main ship channel, opposite the reserved channel. More testing is recommended in this area in order to fine-tune the design and achieve a full test set of successful maneuvers.

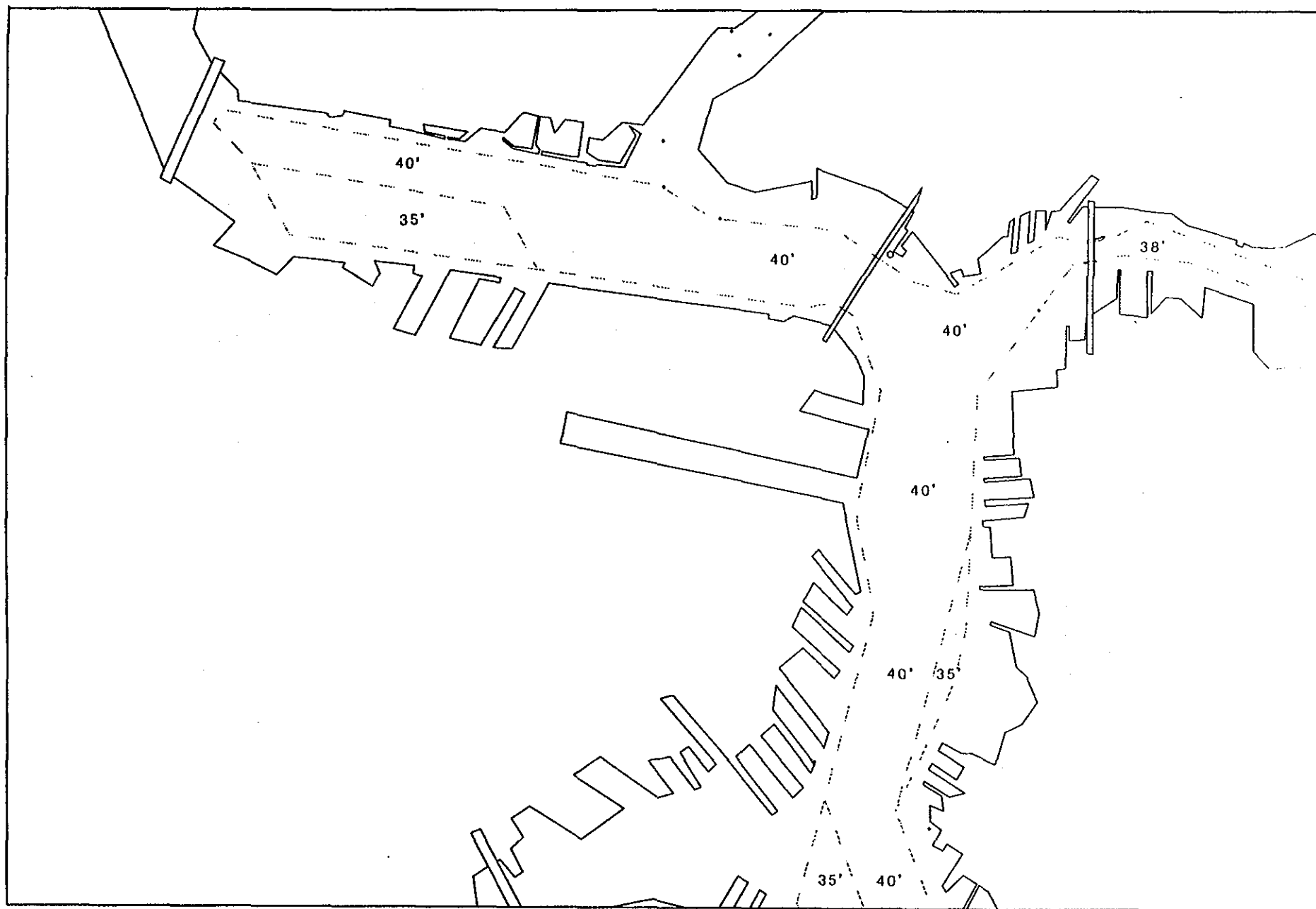


FIGURE 4 Plan 2 Configuration

Section 2

REAL-TIME SIMULATION TESTING PROGRAM

The overall objective of the simulation testing program was to use real-time simulation to evaluate the safety and effectiveness of the proposed improvements to Boston Harbor. Briefly stated, the testing program involved: the creation of accurate simulation models of Boston Harbor and its navigation channels; the creation and validation of ship response models used to test the channels; the participation of five experienced Boston Docking Pilots who conned the simulated vessels in a structured series of tests; and, the collection and analysis of performance data and pilots' expert evaluation of the proposed channel designs.

2.1 TEST-PROGRAM OBJECTIVES

The objectives of this simulation study were to: evaluate the effects of the proposed channel improvements on the safety and efficiency of the deep-draft waterborne commerce in the study area; define specific local modifications to correct any identified navigation problems; and, aid in the refinement of widths for the recommended channels. Therefore, simulated tests of vessel movement throughout the study area effected by the improvements were undertaken. This included the following locations: the Inner Confluence and the Mystic River Channel; the Mystic River approach; the Inner Confluence and the Chelsea River Channel; the Reserved Channel; and the Reserved Channel approach.

2.2 SIMULATION MODELING

Simulation models developed for the study include the gaming area and ship response models. The gaming area is the study area described in the above paragraph, and the ship response models are those vessels that were used for this study, which will be described in detail later in this report. Since objective measures of safety in the marine environment are difficult to establish, the study compared navigation performance (i.e., simulated performance) in the existing channels (baseline condition) to performance in the planned channels. Therefore, versions of the gaming area model that depicted the "existing" (i.e. baseline) Boston Harbor channels as they exist today and the "planned" deepened channels as they will be upon completion of the U.S. Army Corps of Engineers project were both developed. Each simulated gaming area consists of five integrated data bases. These are: visual scene, radar scene, depth/current/bank representation (DCB), visual situation display and plotting presentation.

2.2.1 Visual Database

The visual database consists of water, landmasses, bridges, and important structures in the study area. All aids to navigation are positioned in their exact locations. Other "informal" aids to navigation, such as buildings and other shore structures, are included to elicit realistic pilot shiphandling performance. The visual database was created based on the latest navigation chart for the area as well as engineering drawings provided by the Corps of Engineers and photographs of the area.

The navigation aid positions were provided by the United States Coast Guard and represent the assigned positions of the aids. Proposed changes to the aids to navigation scheme that are scheduled for 1993 are included in the planned version of the database.

The visual scene also depicts the bow of ownship (i.e. the vessel being simulated). During simulation tests, the pilot's perspective of the visual scene is consistent with the height of eye aboard ownship's bridge and the vessel's direction of transit and position. Areas beyond the navigable limits of the simulation model and traffic vessels at berth are also included in the visual database. Discussions with the Boston Docking Pilots were conducted during a site survey to determine which

objects would have to be incorporated in the model to assure adequate visual cues for realistic shiphandling performance.

2.2.2 Radar Database

The radar database was developed in conjunction with the visual scene to provide realistic radar displays of the area. Structures present in the visual database are also represented in the radar database (e.g. landmasses, navigational aids, structures, such as bridges and piers, etc.). Radar returns from other vessels are also simulated.

The radar presentations on the MSI simulators are made via commercial radar repeaters in a realistic planned position indicator (PPI) format. The Full Mission Bridge at the Newport facility is equipped with a Raytheon RAYCAS radar with automatic radar plotting (ARPA) capabilities.

2.2.3 Depth/Current/Bank (DCB) Modeling

The Depth/Current/Bank (DCB) database provides the ship response model with realistic hydrodynamic reactions in the waterways under analysis. It consists of a representation of the unique bank, bottom and current conditions of the waterway. DCB databases of both the existing and planned conditions were created. The current data used in the DCB was generated by the Army Corp of Engineers at the New England Division (NED) and the Waterways Experiment Station (WES) using a TABS-2 hydraulics model. The current values and associated tidal height were calculated for mean spring flood and spring ebb conditions.

Pre-Validation Plots showing the relevant details of the DCB databases were submitted to NED, WES, and MARAD for review and approval. An example of a Pre-Validation plot, showing the associated current vectors, is shown in Figure 5.

The hydrodynamic model automatically accounts for both bank and shallow water effects. These are calculated by on-line programs which determine the appropriate effects based on input parameters including: bank heights, water depth, vessel draft, vessel heading, vessel speed, and distance between vessel and bank wall.

2.2.4 Visual Situation Display and Plotting Presentation

The Visual Situation Display (VSD), and plotting data bases represent aerial perspectives of the channels, aids to navigation, landmasses and important structures present in the model. This aerial or "birds-eye" view, was used on the bridge to give the pilots a better overhead image than was portrayed on the radar. The Visual Situation Display is used to monitor vessel progress during the actual simulation test runs, while the plotting database is used to produce trackplots of each simulated transit for purposes of data presentation and analysis.

2.2.5 Ship Response Models

The ship response model replicates the unique maneuvering characteristics of the real-world ship types being simulated. Six ship types/sizes were selected as test vessels for this study in consultation with the NED, WES, and the Boston Docking Pilots.

The ship response models were validated against representative performance data (turning circles, crash stops, zig-zag maneuvers) for the size, displacement, hull form and propulsion characteristics of the vessels chosen. Engine dynamics, aerodynamic characteristics, bank effect, bottom effect, passing ship effect, propeller and steering engine dynamics are all accounted for in the ship response model. Assist tugs were incorporated into the hydrodynamic calculations of the ship response model as external forces of specified magnitudes and directions.

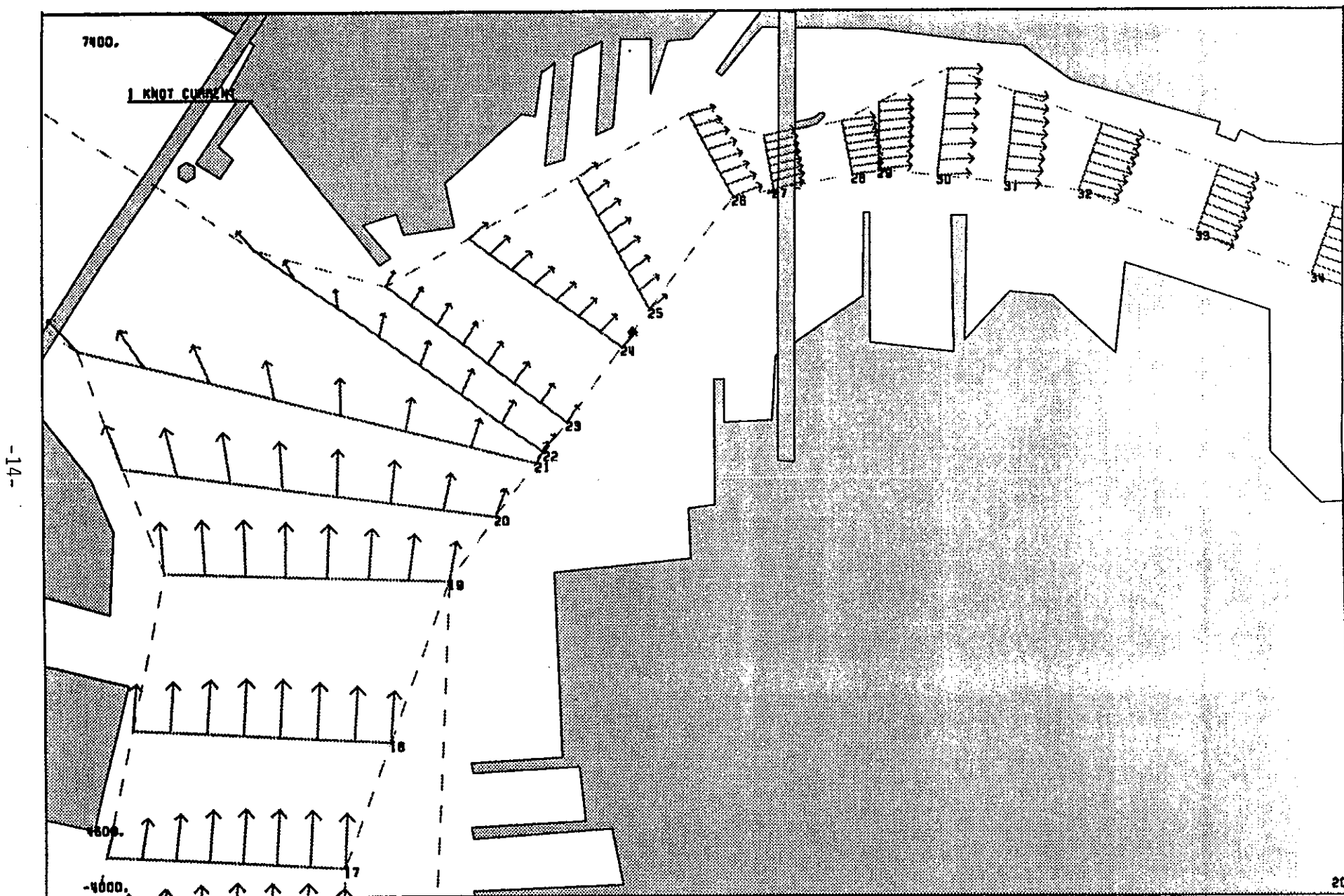


FIGURE 5 Example of a Pre-Validation Plot

Table 1 shows the particular vessel characteristics of the ship models being used. Note that each test vessel is modeled at two drafts for testing in the existing and planned deepened channels. More detailed information on the ship response models can be found in Appendix G.

TABLE 1 Characteristics of Ship Models

| VESSEL TYPE | LENGTH | BEAM | EX DRAFT | PL DRAFT |
|--------------------|---------------|-------------|-----------------|-----------------|
| LNG | 940' | 140' | 38' | 42' |
| 50K DWT Tanker | 692' | 106' | 38.5' | 42' |
| 41K DWT Tanker | 585' | 90' | 38' | 42' |
| 87K DWT Tanker | 840' | 138' | 38' | 45' |
| Panamax Container | 950' | 106' | 36' | 40' |
| APL C8 Container | 788' | 100' | 34.5' | 40' |

2.2.6 Wind Modeling

Wind forces were incorporated into the simulations as a force acting on the ship response model. These forces included horizontal components in the X and Y directions and a resultant moment whose calculations are based on the vessel's aerodynamic profile. Wind forces were automatically calculated based on the wind speed and direction.

The wind conditions used for each scenario were based on Pilot recommendations and published material (in combination with the current conditions) and represented the maximum credible adverse condition under which routine port operations would take place. Loaded tanker operations were conducted without wind, since wind effect is negligible in this condition.

2.2.7 Assist Tug Modeling

During the simulation tests, assist tugs were available to support vessel operations in the confined waterways. The number and power of the tugs that were made available were representative of the tugs currently in use in Boston Harbor. These included 3000HP, 2000HP and 1600HP conventional drive tugs. Each tug could be made fast at numerous locations along the ship length (including bow and stern) on either the starboard side or the port side. The tugs were controlled by the pilot via VHF radio with the simulator operators acting as the tug masters and executing the pilots commands. Realistic operational restrictions and procedures were imposed on tug use.

2.2.8 Validation Procedures

All aspects of the simulation were validated to insure accuracy and functional validity. This included validation of the ship response models, individual databases, scenario premise and test procedures. The validation took place in two-phases. First, in-house validation where MSI staff mariners and engineers rectified any obvious problems in model accuracy, performance and test procedures; then, validation with a subject matter expert, i.e., an experienced Boston Docking Pilot.

Because they are so critical to the study, and because minor problems can easily go undetected, the ship response models underwent a carefully planned in-house validation procedure. The procedure

compares the response model maneuvers with the target ship characteristics. The procedure verified that the following maneuvers meet target criteria:

- Open deep water standard maneuvers (turning, zig-zag, and crash stop)
- Shallow water standard maneuvers (turning, zig-zag, and crash stop)
- Slow speed maneuvers at ship's own power in an open calm environment
- Ship's response to wind effect
- Ship's response to current effect
- Ship's response to bank effect
- Ship's response to tug effects

Databases were checked for accuracy and conformance to data used to create the files. Test scenarios were then run by staff mariners to check for the operational realism and face validity. When all of this is accomplished, the models were ready to be checked and fine-tuned by a Boston Harbor docking pilot.

On-line validation with the pilot took place at MSI's Newport facility from February 18 through 23, 1992. One representative of the Boston Docking Pilots performed the validation. During the course of the on-line validations, the ship response models, databases, and test procedures, were modified and fine-tuned per the validation pilot's recommendations. Such things as scenario starting conditions, e.g., ownship speed, ownship heading, ownship position, etc., were tested and finalized. The entire test program was reviewed and all details finalized in preparation for the on-line test runs.

2.3 TEST PROGRAM DESIGN

The test scenarios and design vessels used for this study were selected to represent "the maximum credible adverse situation". The analysis of these scenarios could then be safely extended to encompass the full operational range e.g., better environmental conditions, less radical ship maneuvers, increased tug support, smaller and/or more maneuverable ships, etc., and insure that the project could provide the anticipated economic benefits. This approach provided a built in safety factor, that was taken into account when results were interpreted.

Table 2 shows the tests that each pilot performed. The tests were selected to optimize simulator usage and, at the same time, address the design and safety issues of concern to the NED. Scenarios, therefore, included transits through Mystic River, Chelsea River, and Reserved Channel and appropriate segments of adjoining channels. The test vessels used in each area were selected based on the present/anticipated vessels that would call at the terminals served by the Federal project.

The testing program examined only loaded ship operations since lightly loaded or ballasted ship operations would not be affected by the proposed improvements. Ships were tested at deeper drafts in the proposed channels, and it was assumed that the loaded ships will continue to take advantage of the tides and attempt to turn in the turning basin at slack water. An exception to testing only flood tide conditions was made for the Reserved Channel where tests of container ship entry and exit included ebb currents.

The test scenarios are described in more detail in the following sections.

2.3.1 Mystic River and Approaches

The testing of the improvements to the Mystic River and approaches included the portion of the Main Ship Channel north of Pier 10, the Inner Confluence Area, the portion of the Chelsea River used by vessels backing into the Mystic River (up to the McArdle Bridge), and the Mystic River. The wider and deeper approach channel to the Mystic River that included deepening the existing 35' section of

TABLE 2 Simulation Test Program

| | MYSTIC RIVER | | CHELSEA RIVER | RESERVED CHANNEL | |
|----------------------------------------------------|----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| E X I S T I N G | 410 LNG Nose into Chelsea River, back to Distrigas pier | | 417 50 K Lower Reach Turn through McArdle Bridge, dock at Mobil | 421 87 K Start in Main Ship Channel, turn and back into Reserved Channel | 425 Panamax Pull away from dock, maneuver around berthed vessel, exit into Main Channel |
| | 412 87 K Inbound Head into Mystic River to Exxon pier | | 419 41 K Upper Reach Pass Through Chelsea Bridge, turn, dock at Gulf Oil | (1) 423 Panamax Start in Main Ship Channel, turn and back into Reserved Channel | (1) 427 Panamax Pull away from dock, maneuver around berthed vessel, exit into Main Channel |
| P L A N N E D | 411 LNG Turn in expanded inner confluence area and back to Distrigas pier | 416 APL-C8 Pull away from Massport Dock, turn, and head into inner confluence | 418 50 K Lower Reach Turn through McArdle Bridge, dock at Mobil | 422 87 K Start in Main Ship Channel, turn and back into Reserved Channel | 426 Panamax Pull away from dock, maneuver around berthed vessel, exit into Main Channel |
| | 413 87 K Inbound to Exxon | | 420 41 K Upper Reach Pass Through Chelsea Bridge, turn, dock at Gulf Oil | (1) (2) 424 Panamax Start in Main Ship Channel, turn and back into Reserved Channel | (1) 428 Panamax Pull away from dock, maneuver around berthed vessel, exit into Main Channel |
| | 414 87 K-plan2 Inbound to Exxon | | | | |

Note: (1) indicates spring ebb tide

(2) indicates same scenario repeated using alternate maneuvering strategy

the Main Ship Channel to 40' downstream of the Inner Confluence was also tested. This is shown in Figure 4 and has been designated as Plan 2. The specific test conditions were as follows.

Scenario 410-Existing vs. 411-Planned

LNG ship inbound, start off of pier 10 in the Main Channel, nose into Chelsea River, back into Mystic River and prepare to dock port side to the Distrigas pier.

Initial Conditions: Speed: 3 kts
 Heading: 003 degrees

Pertinent Traffic Ships: Tanker (800' x 105') at Exxon pier
 Container Ship (950' x 106') at Moran dock
 Tanker (588' x 100') at Atlantic Fuel

Environment: Current: Spring Flood
 Wind: NW 15 kts
 Visibility: Clear

Tugboat Configuration: 6 tugs - See Table 3, Initial Tug Setup

Scenario 412-Existing vs. 413-Planned & 414-Plan 2

87K Tanker inbound, start off of Charles River in Main Channel, head into Mystic River and prepare to dock starboard side to the Exxon pier.

Initial Conditions: Speed: 3 kts
 Heading: 015 degrees

Pertinent Traffic Ships: LNG (940' x 140') at Distrigas pier
 Container Ship (950' x 106') at Moran dock

Environment: Current: Spring Flood
 Wind: None
 Visibility: Clear

Tugboat Configuration: 3 tugs - See Table 3

Scenario 416-Planned (no baseline)

APL-C8 Container Ship outbound, start port side to Moran dock, pull away from dock, turn and head into the Inner Confluence area.

Initial Conditions: Speed: 0 kts
 Heading: 278 degrees

Pertinent Traffic Ships: Tanker (800' x 105') at Exxon pier

Environment: Current: Spring Flood
 Wind: NW 15 kts
 Visibility: Clear

Tugboat Configuration: 2 tugs - See Table 3

TABLE 3 INITIAL TUG SETUP

| SCENARIO | HORSEPOWER | INITIAL POSITION |
|-----------|------------|------------------|
| 410, 411 | 3000 | SB |
| | 3000 | PB |
| | 2000 | SQ |
| | 1600 | SQ |
| | 2000 | PQ |
| | 1600 | PQ |
| 412 - 414 | 3000 | PB |
| | 2000 | SB |
| | 1600 | PQ |
| 416 | 2000 | SB |
| | 2000 | SQ |
| 417, 418 | 3000 | PB |
| | 1600 | SB |
| | 1600 | SQ |
| 419, 420 | 3000 | SB |
| | 1600 | PB |
| | 1600 | SQ |
| | 1600 | PQ |
| 421, 422 | 3000 | PB |
| | 2000 | SB |
| | 1600 | SQ |
| 423, 424 | 3000 | PB |
| | 2000 | SB |
| | 2000 | SQ |
| | 1600 | SQ |
| 425 - 428 | 3000 | PB |
| | 2000 | PQ |

PB = Port Bow
PQ = Port Quarter

SB = Starboard Bow
SQ = Starboard Quarter

2.3.2 Chelsea River and Approaches

The simulation of the Chelsea River improvements included the portion of the Main Ship Channel north of Pier 10, the Inner Confluence Area, and the Chelsea River to the turning basin above the Gulf Oil facility. Two bridges crossing the Chelsea River present potential navigation problem areas in this reach. The McArdle Bridge, located in the bend where the Chelsea River meets the Inner Confluence, has a horizontal clearance of 175' (which does not restrict the beam of ships in the lower reach of the river), however, pilots prefer that vessels not exceed 106' in beam and 630' in length due to the curvature of the channel and presence of the bridge in this reach. The Chelsea Street Bridge has a horizontal clearance of 96' and limits the beam of vessels that can transit the upper reach. There currently is a beam restriction at the bridge of 90.5' during the day and 85.5' at night. Local pilots have expressed concern for vessel safety during the upstream and downstream approaches to both bridges.

The Chelsea River was simulated using two different vessels. A larger ship (50K Tanker) will be used to transit the lower reach from the Main Ship Channel to the Chelsea Street Bridge and to examine the approaches to the McArdle Bridge. A smaller ship (41K Tanker) was used to transit the upper reach, to examine the approaches to the Chelsea Street Bridge and to test turning operations in the turning basin. The specific test conditions were as follows.

Scenario 417-Existing vs. 418-Planned

50K Tanker inbound, start below pier 10 in Main Channel, turn through McArdle Bridge and prepare to dock starboard side to the Mobil Terminal.

Initial Conditions: Speed: 3 kts
 Heading: 003 degrees

Pertinent Traffic Ships: Tanker (800' x 105') at Eastern Minerals pier
 Tanker (588' x 100') at Atlantic Fuel

Environment: Current: Spring Flood
 Wind: None
 Visibility: Clear

Tugboat Configuration: 3 tugs - See Table 3

Scenario 419-Existing vs. 420-Planned

41K Tanker inbound, start inbound of McArdle Bridge, pass through the Chelsea Street Bridge, turn in turning basin and prepare to dock starboard side to the Gulf Terminal.

Initial Conditions: Speed: 4.5 kts
 Heading: 111 degrees

Pertinent Traffic Ships: Tanker (711' x 76') at Mobil pier
 Tanker (711' x 76') at Gibbs pier

Environment: Current: Spring Flood
 Wind: None
 Visibility: Clear

Tugboat Configuration: 4 tugs - See Table 3

2.3.3 Reserved Channel and Approaches

The simulation of the Reserved Channel improvements included portions of the Main Ship Channel from the second turn inbound to the Reserved Channel, and the Reserved Channel. The 87K Tanker and Panamax container ship were used to test the improvements.

Scenario 421-Existing vs. 422-Planned

87K Tanker inbound, start at second turn in Main Ship Channel, slow to turn, back into Reserved Channel and prepare to dock starboard side to the Coastal South Boston pier.

Initial Conditions: Speed: 5 kts
 Heading: 267 degrees

Pertinent Traffic Ships: Destroyer Tender (620' x 85') at Castle Island Berth 16

Environment: Current: Spring Flood
 Wind: None
 Visibility: Clear

Tugboat Configuration: 3 tugs - See Table

Scenario 423-Existing vs. 424 & 424A-Planned

Panamax Container Ship inbound, start at second turn in Main Ship Channel, slow to turn, back into Reserved Channel and prepare to dock starboard side to Castle Island Berth 11.

Initial Conditions: Speed: 4 kts
 Heading: 267 degrees

Pertinent Traffic Ships: Destroyer Tender (620' x 85') at Castle Island Berth 16

Environment: Current: Spring Ebb
 Wind: NW 10 kts
 Visibility: Clear

Tugboat Configuration: 4 tugs - See Table 3

Scenario 425-Existing vs. 426-Planned

Panamax Container Ship outbound, start starboard side to Castle Island Berth 11, pull away from dock, maneuver around another berthed container ship and exit into the Main Channel.

Initial Conditions: Speed: 0 kts
 Heading: 089 degrees

Pertinent Traffic Ships: Container ship (541' X 93') at Castle Island Berth 14
 Destroyer Tender (620' X 85') at Castle Island Berth 16

Environment: Current: Spring Flood
 Wind: NW 15 kts
 Visibility: Clear

Tugboat Configuration: 3 tugs - See Table 3

Scenario 427-Existing vs. 428-Planned

Panamax Container Ship outbound, start starboard side to Castle Island Berth 11, pull away from dock, maneuver around another berthed container ship and exit into the Main Channel.

Initial Conditions: Speed: 0 kts
 Heading 089 degrees

Pertinent Traffic Ships: Container ship (541' x 93') at Castle Island Berth 14
 Destroyer Tender (620' x 85') at Castle Island Berth 16

Environment: Current - Spring Ebb
 Wind - NW 15 kts
 Visibility - Clear

Tugboat Configuration: 3 tugs - See Table 3

2.4 PILOT PARTICIPATION

A total of five pilots participated in the simulation study. Four of the pilots are employees of Boston Towing and Transportation, a local tugboat operator. The fifth pilot is a recently retired Boston Docking Pilot. Individual test pilots are identified as Pilots 1 through 5.

The first pilot traveled to Newport and spent four days running through the test program on the simulator. The following four pilots traveled to Newport in teams of two, with each team spending five days on the simulator. Each pilot performed the full series of tests shown in Table 2. All of these simulations were conducted on the Full Mission Bridge simulator. To mitigate the effects of run order on pilot performance, the scenario run order was counterbalanced so that each participating pilot performed an individual test scenario in a different sequence.

The pilots that participated in teams rotated simulation runs so that while one pilot was involved in a simulation, the other pilot was taking a break. This helped to minimize the fatigue experienced by the pilots and is more representative of the workload they experience in the real world. The pilot who was on break was not permitted to observe the other pilot's performance. The first pilot, who participating alone, was allowed rest periods so consistency was maintained throughout the test program.

The real-time simulation tests were run in March and April of 1992 and 95 real-time simulation tests were successfully completed.

2.5 REAL-TIME SIMULATION PROCEDURES

Set procedures were used in the real-time simulations to ensure a structured and consistent conduct of the tests. This included set procedures for: an initial briefing before the start of simulations, the on-line simulation runs, and the final debriefing, after all of the simulations were completed. The key procedural elements, which formalized and controlled the test program, were as follows.

2.5.1 Experiment Briefing

Upon arrival at MSI's simulator facility, each pilot was given a briefing folder which contained a description of the test plan and information needed for the test pilot to accomplish his task. A formal briefing followed, with the briefing folder used as a guide. It was stressed that a pilot's individual performance or expertise was not under evaluation, but rather that his skills would be used as a benchmark against which the safety and efficiency of the proposed waterway designs would be evaluated.

The key topics that were covered during the briefing included:

- Objectives and scope of the study
- Channel designs to be simulated
- Ships to be simulated, and associated principal dimensions and maneuvering characteristics
- Environmental conditions to be simulated
- Bridge procedures, e.g., communications, engine and helm orders, etc.
- Test program and data collection procedures
- Assist tug availability, horsepower, procedures for using, and limitations

2.5.2 Familiarization Exercises

After the experiment briefing, and prior to conducting any of the test runs, the pilots were brought to the simulated bridge and given the opportunity to familiarize themselves with the bridge and the operation of the equipment. The pilots then conned the simulated vessels during familiarization exercises to become acquainted with the simulator environment, maneuvering characteristics of the test ships, and bridge procedures.

2.5.3 Test Procedures

Prior to the start of each scenario, each pilot was briefed. The briefing included information pertaining to the ship he would be conning, the environmental conditions, the channel to be transited, and the general objective of the scenario. Once the simulation started, the pilot had full control over the vessel's rudder and engines, and the actions of the assist tugs. An experienced helmsman was provided for all simulations to steer the ship and respond to the pilot's helm and engine orders. The MSI study team observed all the simulated runs from a control and observation center.

After each scenario, the test pilot was asked to fill out a short debriefing form which contained questions regarding the just completed transit. There was also a space for the pilot to comment on any aspect of the previous transit.

2.5.4 Assist Tug Use

Assist tugs were made available to the Docking Pilots during all simulations. Table 3 lists the initial configuration of the tugs for each scenario. The pilots were instructed in the use of the assist tugs and applicable procedures and limitations. The objective of the procedures and limitations imposed was to insure that the tug support, so far as practical, accurately simulated the real-world operational conditions. Pilots had complete control over the placement and maneuvering of the tugs, subject to the following operational procedures and limitations:

- Tugs were controlled via bridge mounted VHF radio. Orders were acknowledged by the tug captains (Control Station Operator) via the VHF. When asked, the tug captains provided the pilot with information regarding the vessel's clearance to buoys, piers, etc. The tugs could be ordered to operate at any angle relative to ownship.
- All assist tugs kept pace with ownship and did not exert any forces upon ownship until ordered into action.
- Realistic time delays were incorporated into the simulations whenever a pilot requested a tug to come alongside, shift position, or let go.

2.5.5 Data Collection Procedures

During each scenario, data was collected for later analysis. This included both objective data recorded by the simulation computers, subjective data in the form of pilot's comments on the debriefing forms, and notes taken by the MSI study team. The following basic parameters, were recorded by the simulation computers at a rate of once every second:

- Course
- Forward Velocity
- XO (location on x axis)
- Engine RPM
- Rudder angle
- Rate of Turn
- Heading
- Lateral Velocity
- YO (location on y axis)
- Resultant tug force x axis
- Resultant tug force y axis
- Tug Order

These basic parameters were used in the calculation of the composite measures of vessel performance used in the analysis and to generate the trackplots and composite trackplots showing the vessel trajectories and swept path.

2.5.6 Experiment Debriefing

After completing the set of simulation runs, each pilot filled out an Experiment Debriefing form. This form requested detailed information regarding the pilot's background and experience, the accuracy and fidelity of the simulation models, aspects of the simulation modeling that may have impacted upon performance, and the pilot's opinion of the channel designs and operational procedures under analysis.

Section 3

DATA REDUCTION AND ANALYSIS

Data collected during the course of the real-time simulation runs was compiled and analyzed. This included the utilization of computer programs to generate measures of performance. Data from several categories of performance measures was prepared and analyzed. This included:

- Trackplots of individual transits showing proximity of vessel-to-channel boundaries, landmasses and fixed objects.
- Composite trackplots of multiple transits under a given set of test conditions.
- Ship reserve control force margins.
- Tugboat activity measures and reserve control margins.
- Pilots' expert evaluation of the simulated transits.

3.1 TRACKPLOTS

An individual trackplot is a graphically represented time history of the vessel's transit. It shows an outline of the path of the vessel as well as landmasses, navigation aids, and Federal Channel boundaries. An analysis of an individual trackplot quickly conveys a variety of information, including proximity to channel boundaries, fixed objects, and other vessels, as well as turning radiuses and frequency of corrective action required for a maneuver. Individual trackplots for all 95 simulated transits are shown in Appendix A.

A composite trackplot is similar but shows an overlay of all vessel transits for a particular scenario. This gives a representation of the envelope of travel for all pilots performing a particular maneuver and is very effective in determining the maneuvering area utilized. Composite trackplots of all 19 scenarios are shown in Appendix A.

3.2 SHIP RESERVE CONTROL

The Ship Reserve Control (SRC) measure was calculated for the test vessels. SRC takes the use of rudder and engine, and combines them together into a single index over time. The index reports on the percent (%) of control forces unused, and thus available to turn (yaw) the vessel. The formula used to calculate SRC is as follows:

$$SRC = \left(1 - \frac{U_{pp}^2(u, v, r, RPM) @ \text{Time } t * d @ \text{Time } t}{U_{pp}^2(u, v, r, RPM_{max}) * d_{max}} \right) * 100\%$$

where:

| | |
|-----------|---------------------------------------------------------------------|
| U_{pp} | is the inflow velocity to rudder, |
| u, v, r | are the ship forward, lateral, and yaw speed with respect to water, |
| RPM | is the propeller speed, |
| d | is the rudder angle applied, |
| max | refers to the maximum available value of the subscripted parameter |

Ship Reserve Control provides an indication of the difficulty of a maneuver under a given set of conditions. A zero value means complete utilization of all available control force with none left in reserve. A value of 100% means that no control forces are being applied to turn the vessel.

Ship Reserve Control was calculated as a continuous function based on the vessel's down track location along a hypothetical trackline that was defined for that purpose. Figures 6 through 8 show the tracklines and down track locations (in increments of 1000') used for the Mystic River, Chelsea River, and Reserved Channel respectively. The average SRC of all Pilots for a particular scenario was calculated as a function of down track distance and the instantaneous mean (i.e., average of all pilots at a specific down track distance) was reported at intervals of 200'. The SRC plots for every scenario are shown in Appendix B.

3.3 TUG RESERVE CONTROL

The Tug Reserve Control (TRC) measure reports the percentage of tug power the pilot has in reserve at any point in a maneuver. This information, combined with the Reserve Control of ownship's engines and rudder, provides a good representation of the difficulty and margin of safety maintained during a particular maneuver.

The tug boat engine settings requested by the pilot were used to calculate the TRC measure. A four level scale corresponding to the full range of tug engine commands was used to calculate the TRC. using the following formula:

$$TRC = \left(1 - \frac{(\text{abs}(\text{tug1}) + \text{abs}(\text{tug2}) + \text{abs}(\text{tug3}) + \dots)}{\text{total \# of available tugs}} \right) * 100\%$$

where:

Tug # equals .25 when power setting is dead slow
 equals .5 when power setting is slow
 equals .75 when power setting is half
 equals 1 when power setting is full

This measure assumes that the Pilot is using the tugs in the most efficient configuration to perform his shiphandling task. The average TRC of all Pilots for a particular scenario was calculated as a function of down track distance and the instantaneous mean (i.e., average of all pilots at a specific down track distance) was reported at intervals of 200'. The TRC plots for all test scenarios are shown in Appendix C.

3.4 PILOTS' EVALUATION

The Pilots' Evaluation of each simulated transit was recorded at its conclusion using a debriefing form. The form was filled out immediately after each test run, so that the data collected was focused on the previous simulated transit and not global issues. The results of these debriefings were grouped by scenario, and descriptive statistics of responses were developed. Forms were customized for each scenario. The plots showing the Pilot Evaluations of Safety are shown in Appendix D, and a sample of a Scenario Debriefing Form is provided in Appendix E.

3.5 INTERPRETING THE RESERVE CONTROL MEASURES

The reserve control measures described in previous sections provide insight into the difficulty and safety of a particular maneuver. However, they cannot be interpreted out of context of the specific maneuver being performed. There are certain limitations that must be taken into account in order to get a clear understanding of what is happening, and these limitations were taken into account during the analysis of the test runs. The implications of these limitations are discussed below.

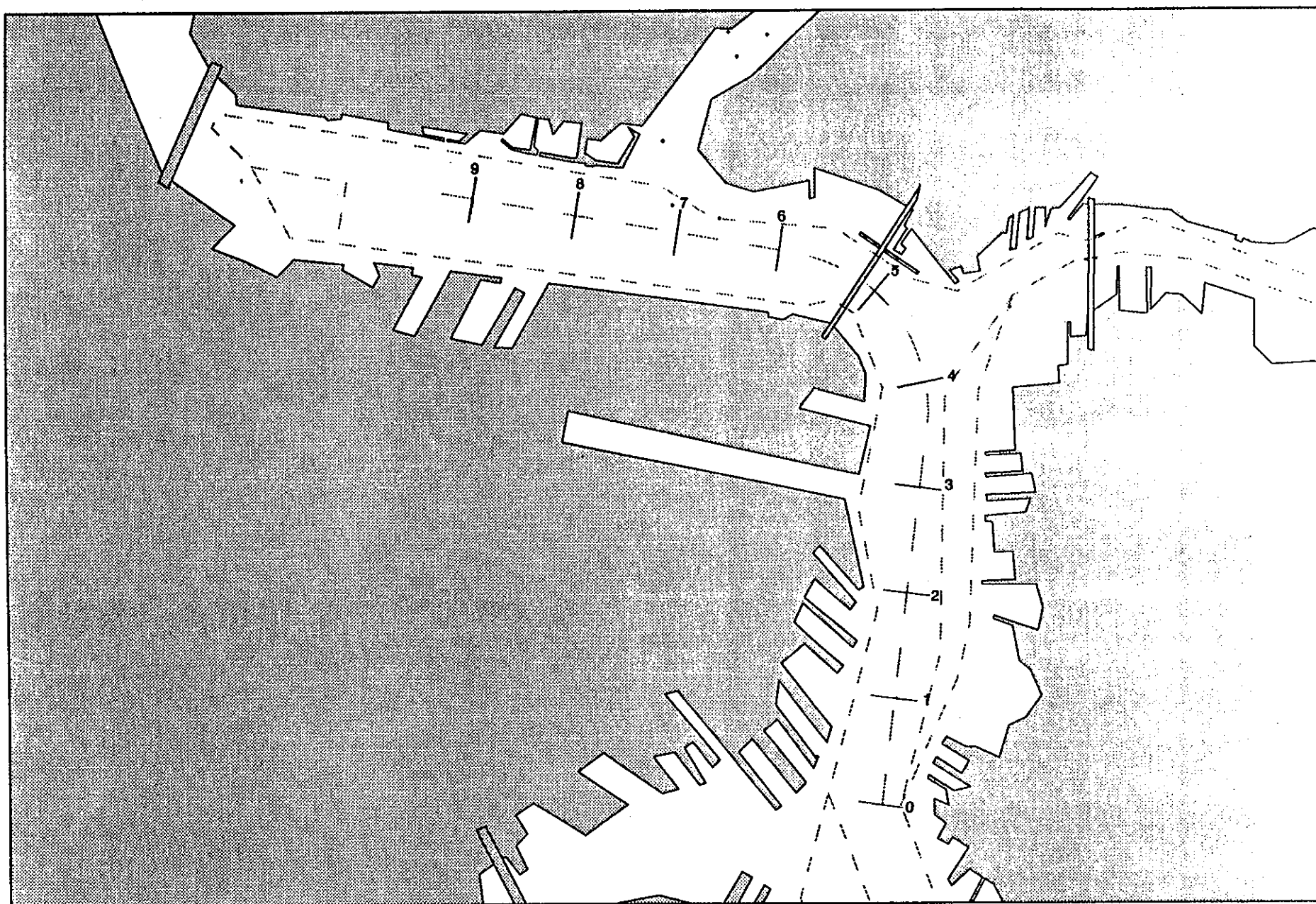


FIGURE 6 Mystic River Trackline (downtrack distances in thousands of feet)

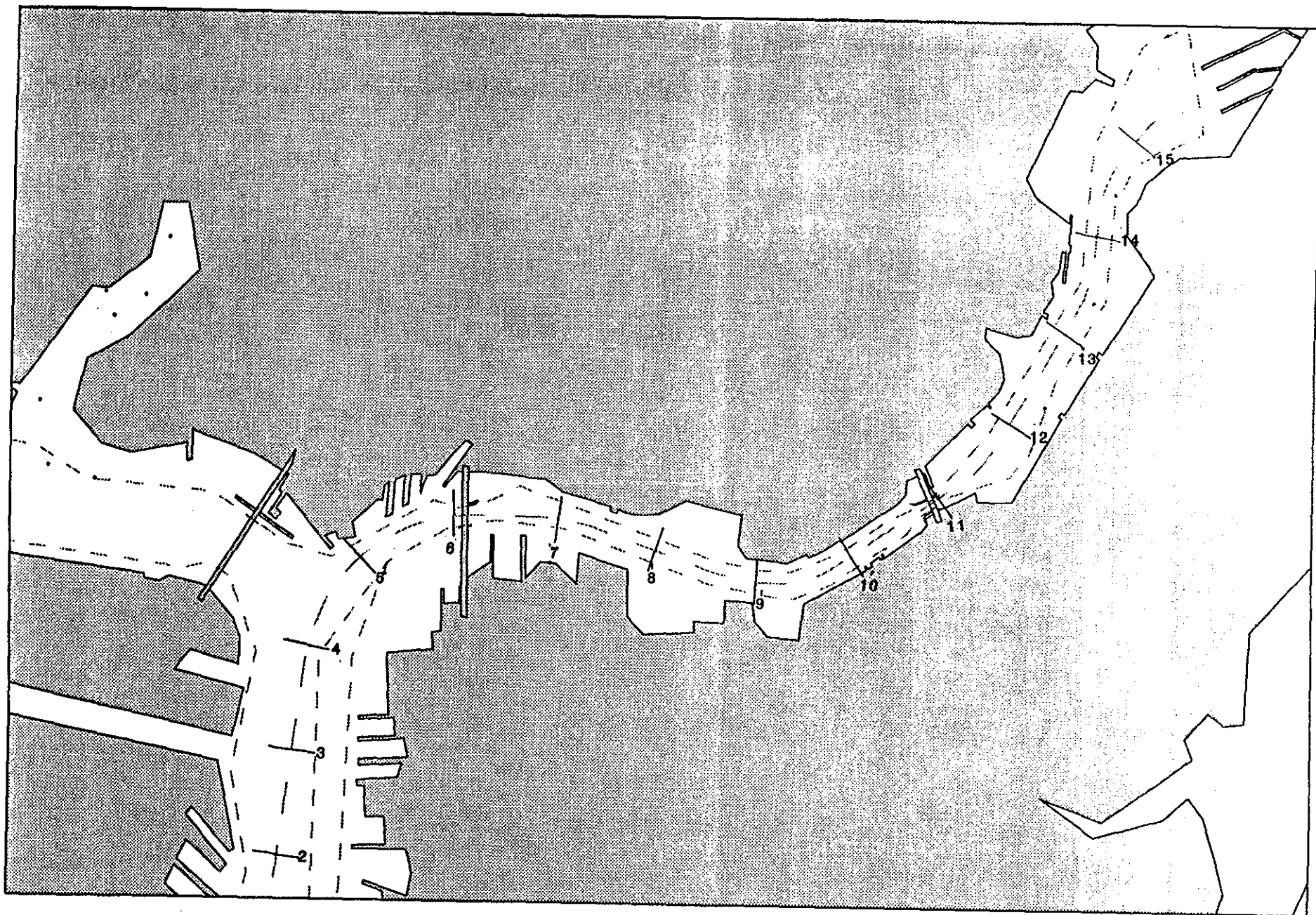


FIGURE 7 Chelsea River Trackline (downtrack distances in thousands of feet)

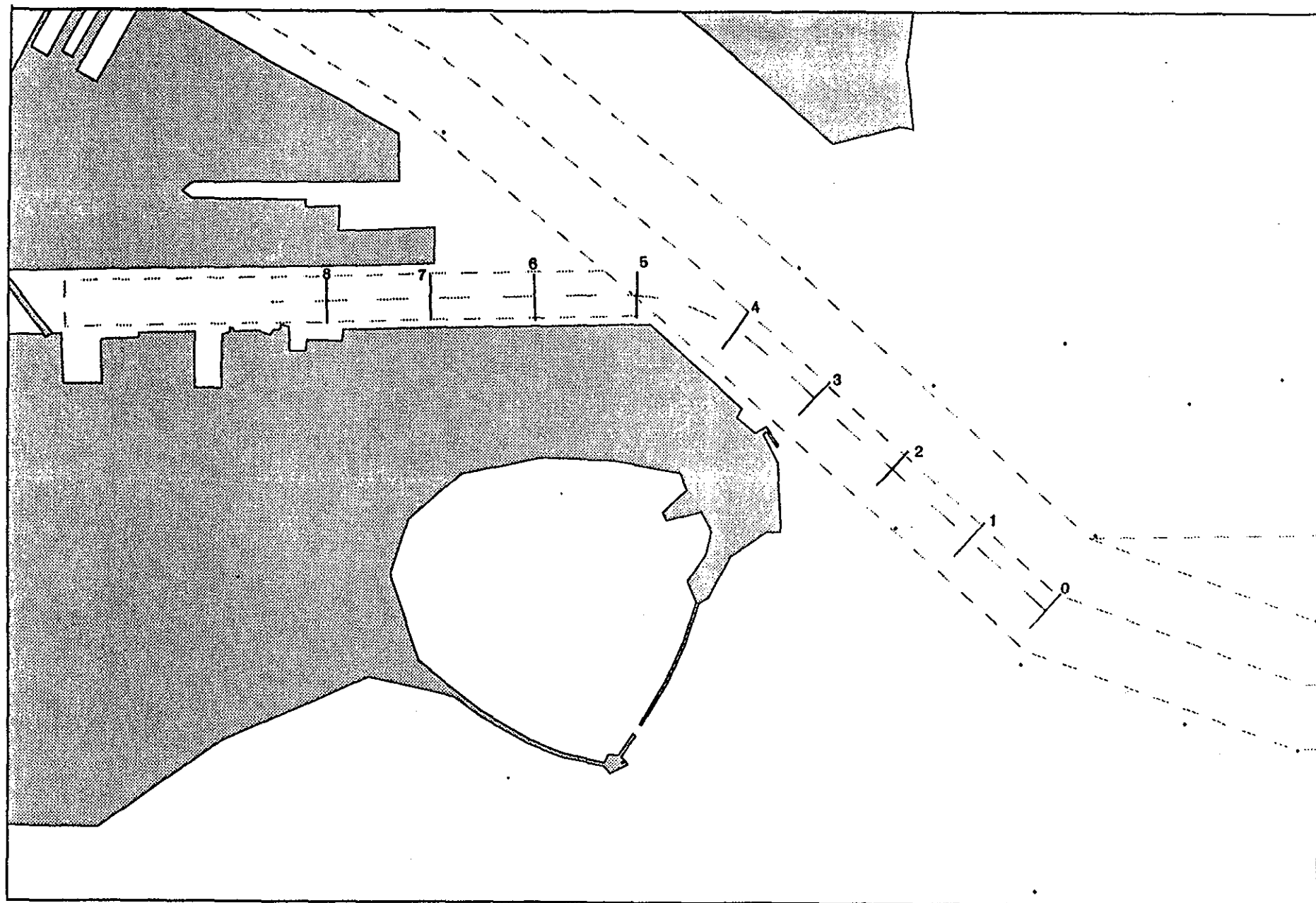


FIGURE 8 Reserved Channel Trackline (downtrack distances in thousands of feet)

The Ship Reserve Control measure is based on engine RPM's (Revolutions Per Minute) and rudder activity. For example, the value of SRC would be 0% if the engine was full ahead and the rudder was hard over. However, a Pilot is not always willing or able to use the full measure of reserve control due to the configuration of the particular waterway. For example, certain maneuvers using the engines at "full ahead" or even "half ahead" will result in excessive speed and put the vessel in danger. This effectively reduces the true available reserve.

Another example is when a maneuver can only be accomplished with tug boat assistance. In this case the vessel's longitudinal speed must be kept low in order for the tugs to work safely and effectively. The tug effectiveness drops off quickly with the increase of the vessel's longitudinal speed, since the tug boat is using more of its power to keep its relative position on the vessel. Due to this relationship between ship speed and tug effectiveness, it can be seen that under certain circumstances SRC and TRC are complementary.

As with SRC, there are factors that must be taken into account when analyzing TRC. For example, in most of the turning maneuvers seen in this study, the Pilots positioned one tug on each bow and worked one tug full ahead to accomplish the maneuver. Even if the tug was having difficulty getting the bow around, the Pilot would be very hesitant in moving the other bow tug around to assist. Based on their experience, it is not wise to do this, since you would not have the ability to check the swing of the vessel once it started turning. Also, time constraints in moving tugs sometimes makes it impossible to get a tug ready to work in time for an emergency. This effectively lowered the amount of power available to accomplish the maneuver (only one effective bow tug), making a 50% TRC more like a 0% TRC.

Ship Reserve Control and Tug Reserve Control are useful numerical measures, however, they can be interpreted properly only when analyzed together with the vessel position data (presented in the trackplots) and the Pilot evaluations.

Section 4 RESULTS AND CONCLUSIONS

The results and conclusions derived from the simulated transits are presented in this section. Specific trackplots are included to demonstrate how the data was interpreted. The Appendices to the Final Report should be referenced if more detailed information is desired.

4.1 MYSTIC RIVER AND APPROACHES

The testing of the improvements to the Mystic River and approaches included the portion of the Main Ship Channel north of Pier 10, the Inner Confluence Area, the portion of the Chelsea River used by vessels backing into the Mystic River (up to the McArdle Bridge), and the Mystic River. A wider and deeper approach channel to the Mystic River that included deepening the existing 35' section of the Main Ship Channel to 40' downstream of the Inner Confluence was also tested. This is shown in Figure 4 and has been designated as Plan 2.

4.1.1 Scenario 410 vs. 411

The existing test scenario (410) involved a Liquefied Natural Gas (LNG) ship loaded to 38' transiting inbound on a flood tide to the Distrigas terminal in the Mystic River. The existing maneuver required that the vessel be turned in the Inner Confluence Area and then backed under the Mystic Bridge to the terminal. Since the flood tide that was modeled had an associated tidal height of 6' above Mean Low Water (MLW), the 35' MLW Mystic River and the 35' MLW side of the Main Ship Channel had an actual depth of 41' and the 40' MLW side of the Main Ship Channel had an actual depth of 46'. The LNG vessel was therefore able to safely use all sections of the Federal channels. The existing channel configuration is shown in Figure 2A.

The planned test scenario (411) was the same as the existing scenario except that the vessel was loaded to 42'. The planned configuration, shown in Figure 3A, calls for deepening most of the Mystic River and an expanded Inner Confluence Area to 40' MLW. The south west quadrant of the Mystic River would not be deepened and would be excluded from the Federal project. The draft of the vessel in the planned scenario, limits vessel movement to the areas maintained at 40' MLW. A wind of 15 knots out of the northeast was used during both the existing and planned scenarios.

The main findings and conclusions derived from the comparison of performance seen in the planned vs. the existing channel configurations and depths are as follows:

The proposed widened Inner Confluence area provides adequate safety for the deeply loaded LNG.

There is a possibility that the loaded LNG can be safely maneuvered in the Inner Confluence Area without the proposed expansion. It is therefore recommended that an unimproved configuration be tested with the more deeply laden vessel.

The area in the southwest quadrant of the Mystic River, which will not be maintained, reduces the safety of the LNG backing maneuver. Most of the test pilots recommended that this area be modified to provide more maneuvering room. A slight tapering of this area is recommended.

Discussion

An analysis of the trackplots in the existing design indicated that the vessel remained within the channel boundaries for all test runs, although there were two occasions when the vessel's stern nearly crossed the channel boundary. All pilots gave safety ratings of "Adequate" to "More than

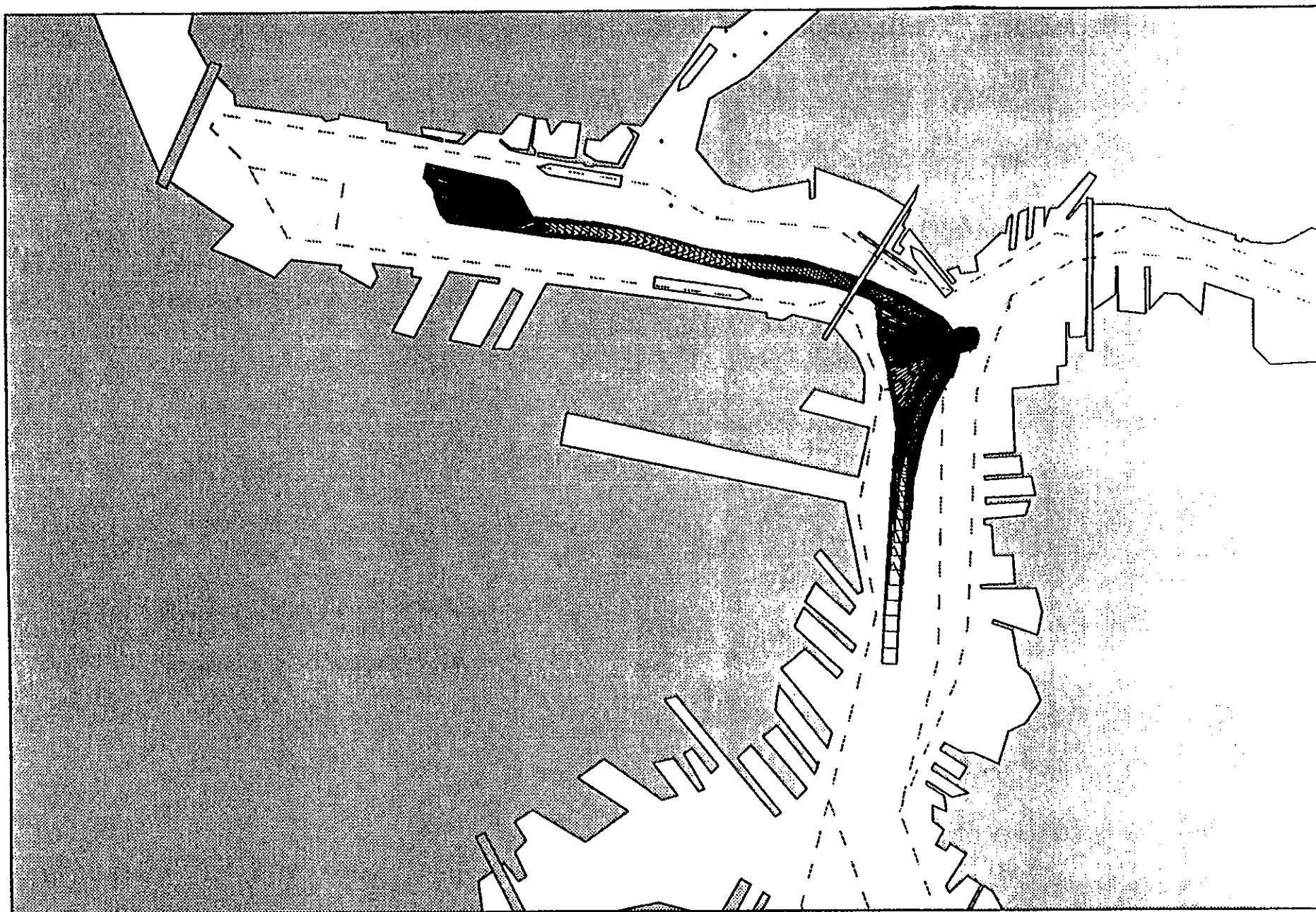


FIGURE 9 Individual Trackplot - Scenario 410 - Existing - LNG

FIGURE 10 Individual Trackplot - Scenario 411 - Planned - LNG

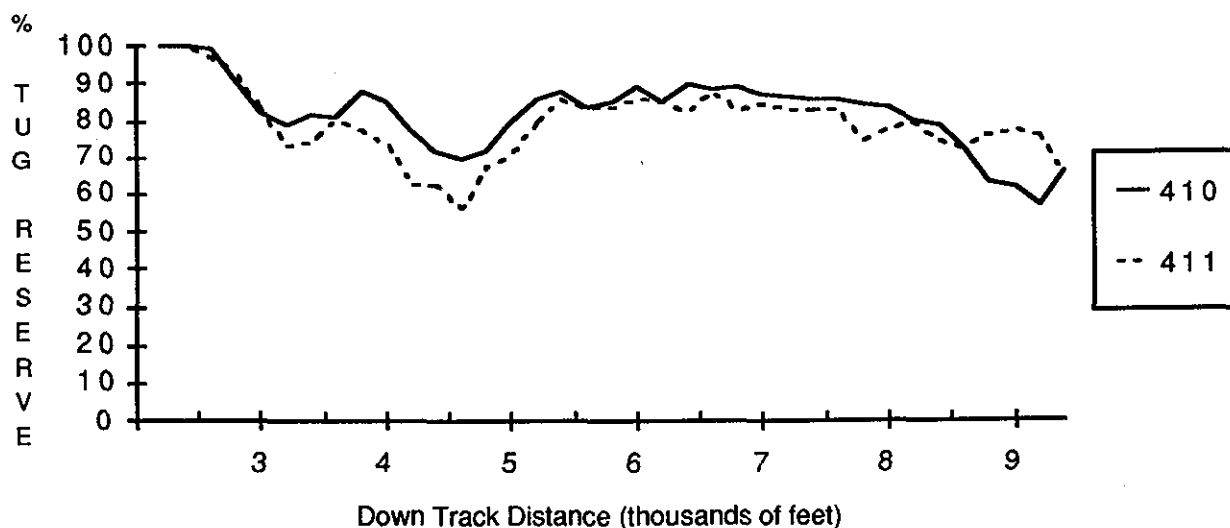
Adequate" for the different phases of the maneuver. Several pilots noted that, on the simulator, there was a tendency to turn the ship earlier and in the real world, the turning maneuver would probably be executed farther into the Inner Confluence. An example of this maneuver is shown in Figure 9.

An analysis of the trackplots in the planned design indicated that the vessel stayed within the channel boundaries during all tests and the expanded Inner Confluence Area led to better positioning in the turn with increased clearances to boundaries. All of the pilots recommended that this design be implemented to insure the safety of the maneuver. The pilots gave "Adequate" to "More than Adequate" safety ratings for all phases of the maneuver except for backing in the Mystic River. Although the track plots indicate good vessel position when the vessel was between the proposed buoy (marking the unmaintained area) and the tanker at Exxon, the consensus among the pilots was that this configuration lowered the margin of safety of the maneuver to a marginal status by forcing the LNG closer to the vessel at the Exxon berth. This could be mitigated by tapering the unmaintained area, allowing more room for the LNG and associated tug boats. Several pilots expressed the opinion that tapering this area was more critical to the safety of the maneuver than expanding the Inner Confluence Area. A representative example of the maneuver in the planned design is shown in Figure 10.

The Ship Reserve Control (SRC) for both the existing and planned maneuvers was very high, indicating that the maneuver was primarily accomplished with tug boats. A comparison of the Tug Reserve Control (TRC) between maneuvers in the existing and planned designs, see Figure 11, shows a slight increase in tug support in the planned condition. This was expected because of the increased displacement of the vessel.

4.1.2 Scenario 412 vs. 413 and 414

Scenario 412 required that the pilots bring an 87K Dead Weight Ton (DWT) tanker to the Exxon berth in the existing Mystic River on a flood tide. The draft of the vessel was 38' and the maneuver consisted of transiting the Main Ship Channel, turning through the Mystic Bridge, and preparing to dock at the Exxon terminal. Due to the height of the tide (+6'), both the 35' MLW or the 40' MLW sections of the Federal channel were usable by the vessel. In Scenario 413, the planned configuration was tested with the same vessel loaded to 45'. This rendered the 35' MLW side of the



**FIGURE 11 Tug Reserve Control - Scenarios 410/411
(mean values, all pilots)**

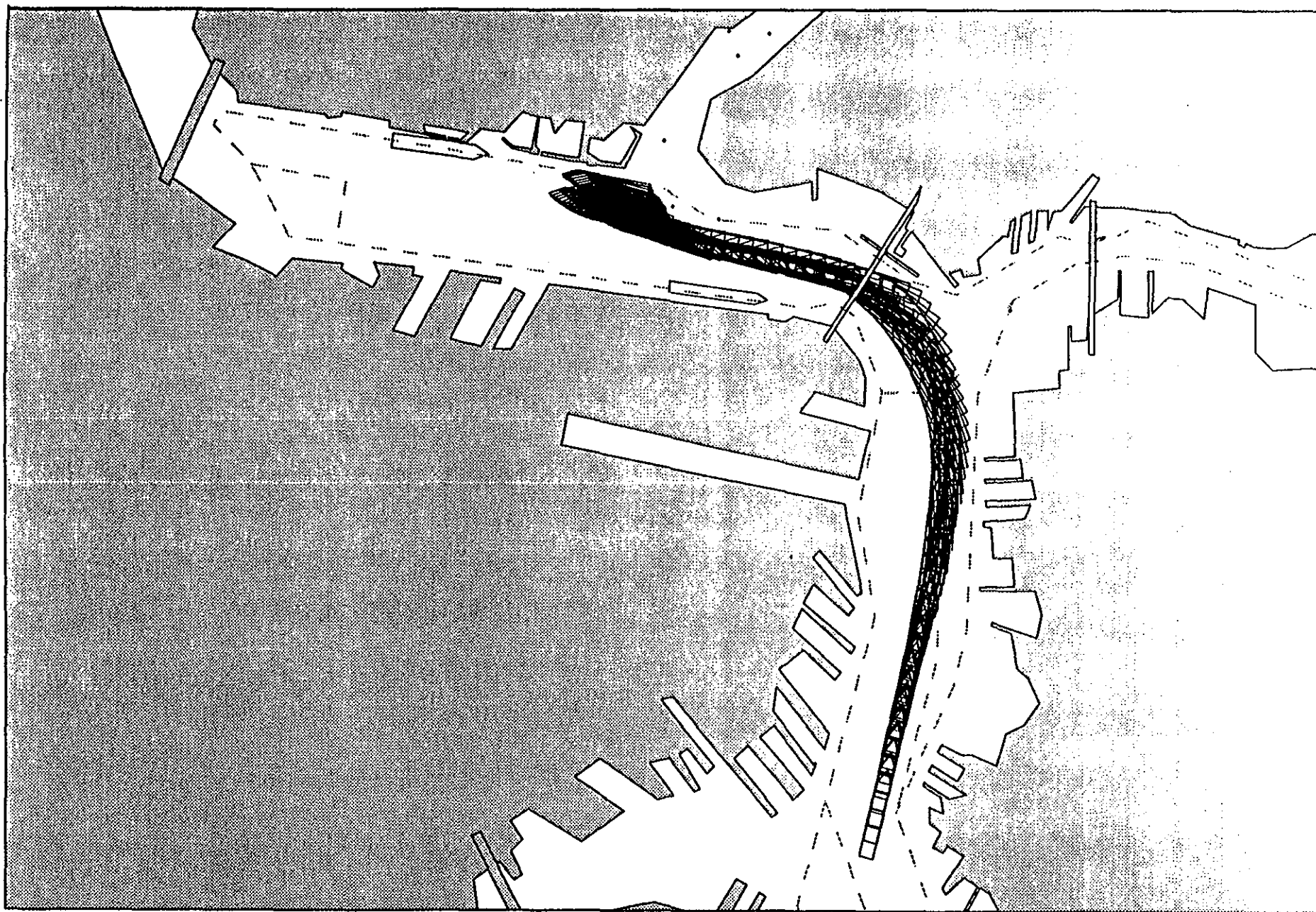


FIGURE 12 Composite Trackplot - Scenario 412 - Existing - 87K Tanker

Main Ship Channel off limits to the more deeply laden vessel. An alternative planned configuration, Plan 2, was tested in Scenario 414. The Plan 2 configuration is shown in Figure 4 and consists of a widening of the 40' MLW Main Ship Channel beginning at the Inner Confluence and proceeding downstream to a position opposite Pier 11.

The main findings and conclusions derived from the comparison of performance seen in the planned vs. the existing channel configurations and depths are as follows:

The maneuvers were successfully completed in the planned configuration, however, the reserve control decreased in the planned configuration.

The results of the numerical analysis along with a strong endorsement by the pilots supports the implementation of Plan 2.

Discussion

The existing maneuver was completed by all pilots without incident and generally received a safety rating of "Adequate". The common strategy was to take the turn wide, which allows the vessel to take a slower and smoother turn. Due to this strategy, all pilots crossed over into the 35' MLW section of the main channel, which did not represent a grounding risk in the existing scenario. A composite trackplot showing all pilots making this maneuver is shown in Figure 12.

Four of the five pilots were able to maintain very good position throughout the turn during the same maneuver in the planned configuration, however, TRC level was substantially lower than that seen in the existing condition. This decrease in reserve control, combined with the increased draft of the vessel, led to slightly decreased safety ratings for the planned configuration. It was difficult for the pilots to know exactly where the 35' MLW half of the channel was because the demarcation between the areas was not marked. The Plan 2 configuration (Scenario 414) provided a safe compromise between control of vessel and channel dimensions. Figure 13 compares the TRC during all three scenarios.

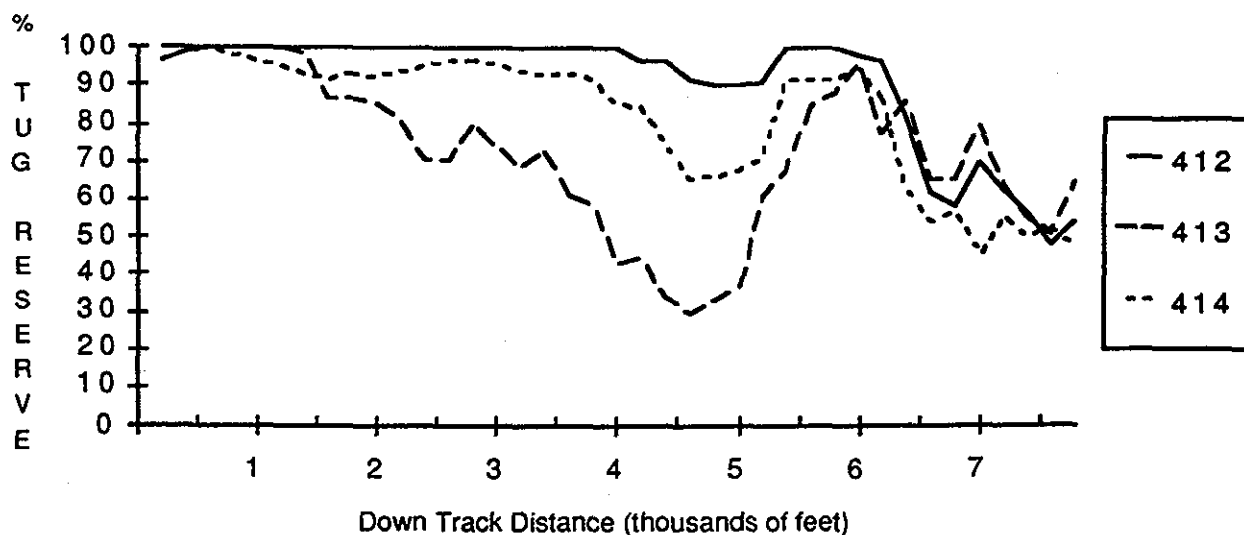


FIGURE 13 Tug Reserve Control - Scenarios 412/413/414
(mean values, all pilots)

Plan 2 was endorsed by the pilots and given "Adequate" safety ratings, as shown in Figure 14. This configuration allowed the pilots to use their existing strategy of taking the turn wide and thus increased TRC over that seen in the planned configuration. Figure 15 shows the SRC for the three maneuvers and indicates that Plan 2 required more of the ship's engines and rudder to accomplish the maneuver, but still left a sufficient amount of control force in reserve. A composite trackplot showing all tests in the Plan 2 configuration is shown in Figure 16.

Note that if the expansion of the Inner Confluence Area is not included in the project, then implementation of Plan 2 is required for the safety of the tanker turning maneuver. It was also noted

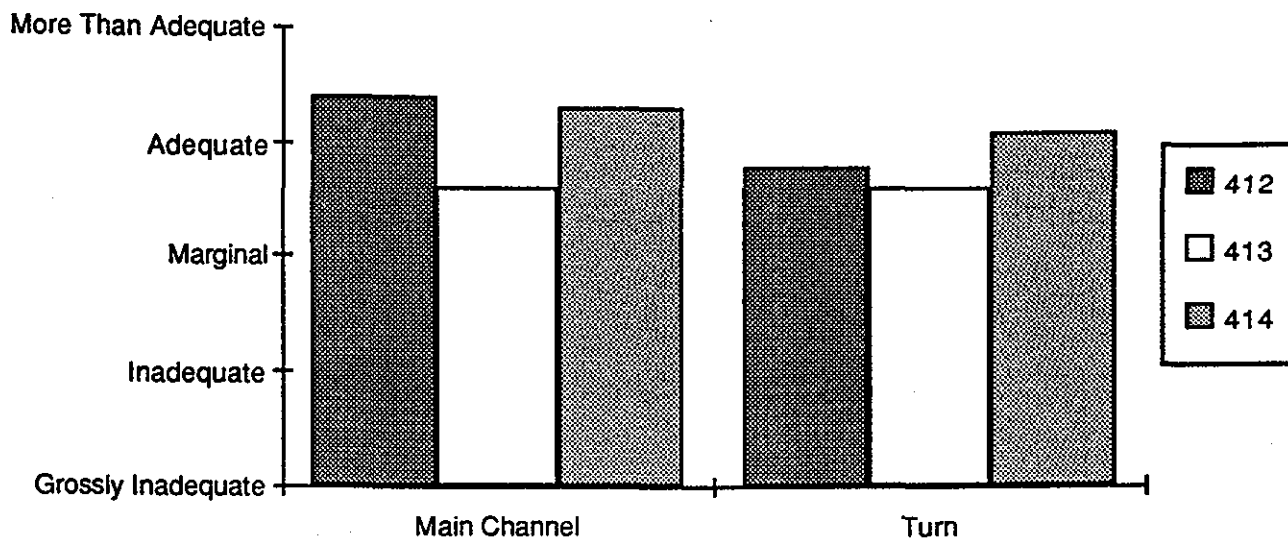


FIGURE 14 Pilot Evaluation - Margin Of Safety - Scenarios 412/413/414
(mean values, all pilots)

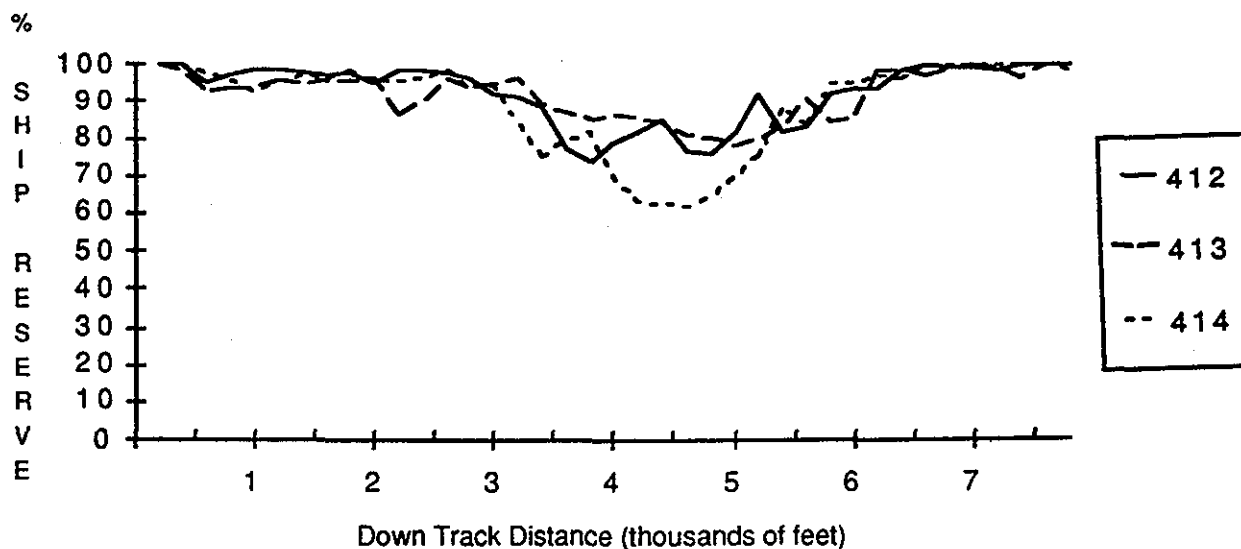


FIGURE 15 Ship Reserve Control - Scenarios 412/413/414
(mean values, all pilots)

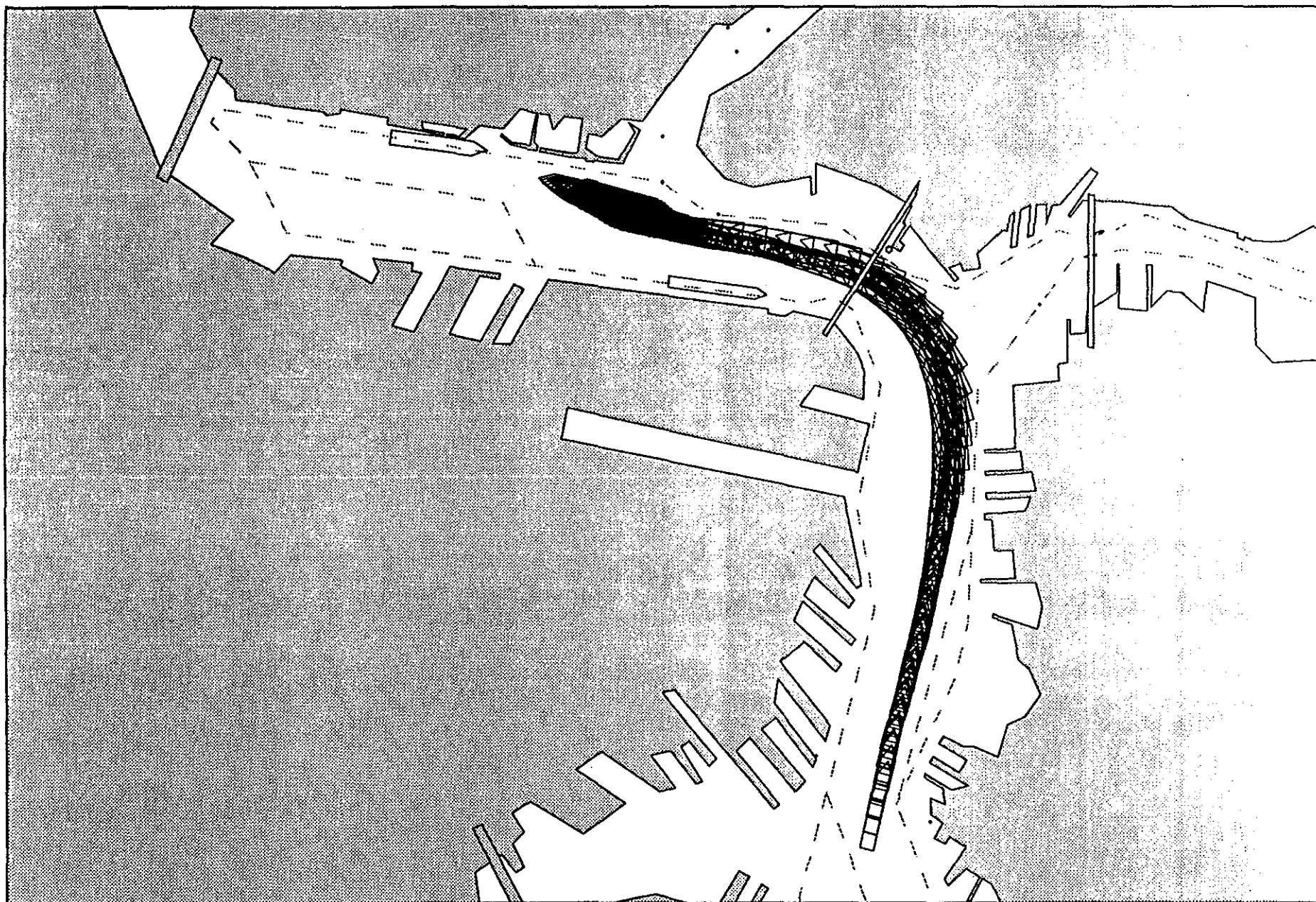


FIGURE 16 Composite Trackplot - Scenario 414 - Plan 2 - 87K Tanker

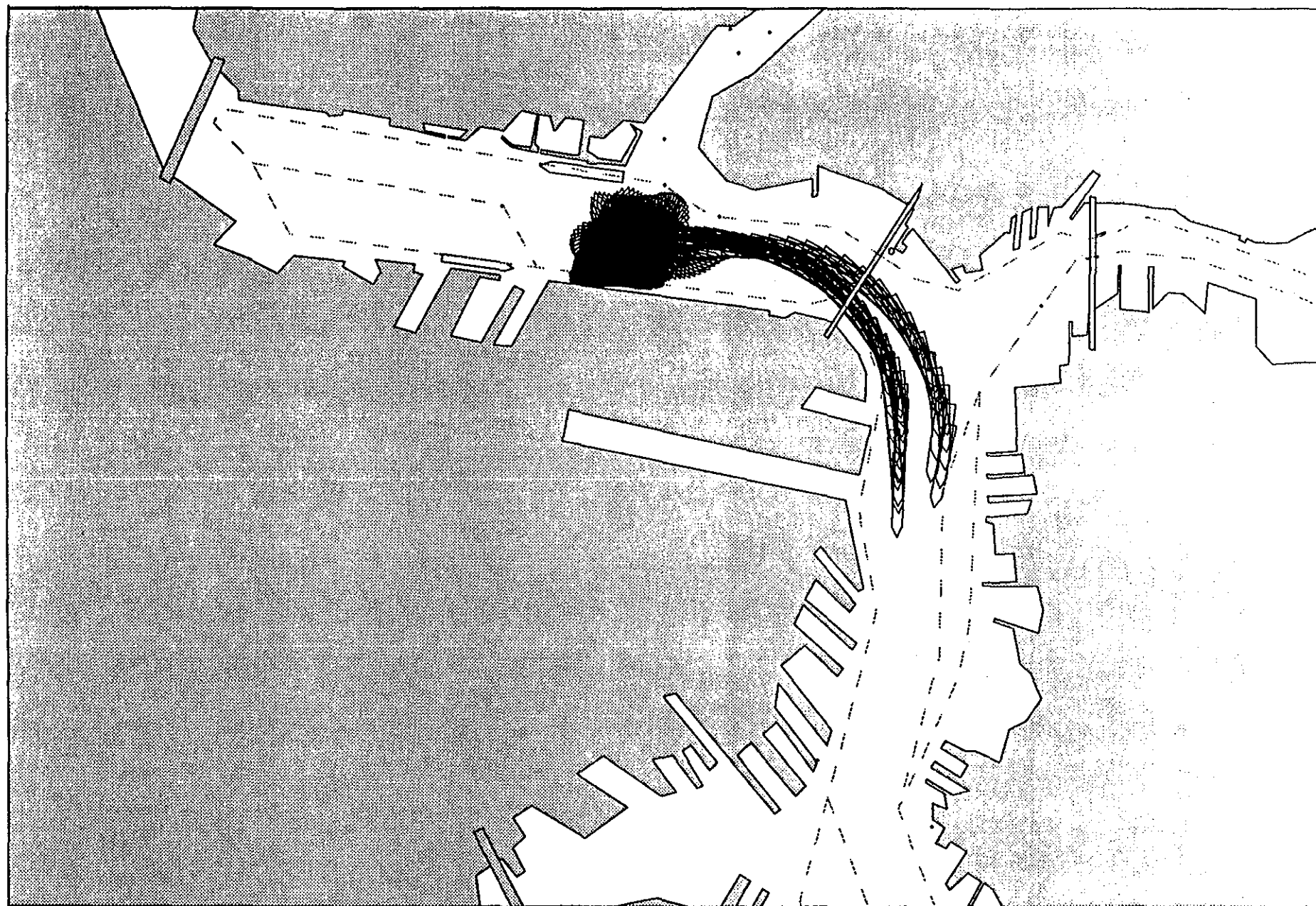


FIGURE 17 Composite Trackplot - Scenario 416 - Planned - C8

by one of the pilots that loaded outbound container vessels could also benefit from the implementation of Plan 2 since they would be able to take a wider turn out of the Mystic River during a wide range of tidal heights.

4.1.3 Scenario 416

In Scenario 416, an APL C8 with a bridge forward configuration, container ship was tested turning in the Mystic River in the planned configuration on the flood tide. The pilots were required to turn the vessel, which was loaded to 40', without entering into the unmaintained South West quadrant, and then enter the Main Ship Channel. A tanker was also placed at the Exxon dock to create a worst case situation. This test was not directly compared to an existing/baseline condition. A wind of 15 knots from the North West was used for this test.

The main findings and conclusions derived from these tests are as follows:

The planned design provides adequate room to safely turn vessels of this size in the Mystic River.

Discussion

The track plots of this scenario showed that all the pilots maintained good position throughout the turn, and, in general, the pilots rated the safety of this maneuver "Adequate". A composite trackplot of this scenario is shown in Figure 17. Two different strategies were used for this maneuver: three pilots turned the vessel clockwise, and two pilots chose to turn the vessel counter clockwise. The counter clockwise strategy tended to keep the vessel a little further away from the berthed vessel at Exxon and resulted in good position through the Mystic Bridge. The clockwise maneuver resulted in the pilots leaving the Mystic River much closer to the south channel boundary than they had anticipated, which may have been due to the 15 knot wind from the North West. These pilots rated the margin of safety as "Adequate" while turning through the Mystic Bridge, which indicates that they do not anticipate a problem making this turn in the actual harbor. A margin for error must be taken into consideration due to the fact that the pilots were unfamiliar with a bridge forward vessel.

Since the majority of the maneuver was accomplished at the same down track distance, Figure 18 shows the TRC as a function of elapsed time. While TRC was very low, the pilots indicated that

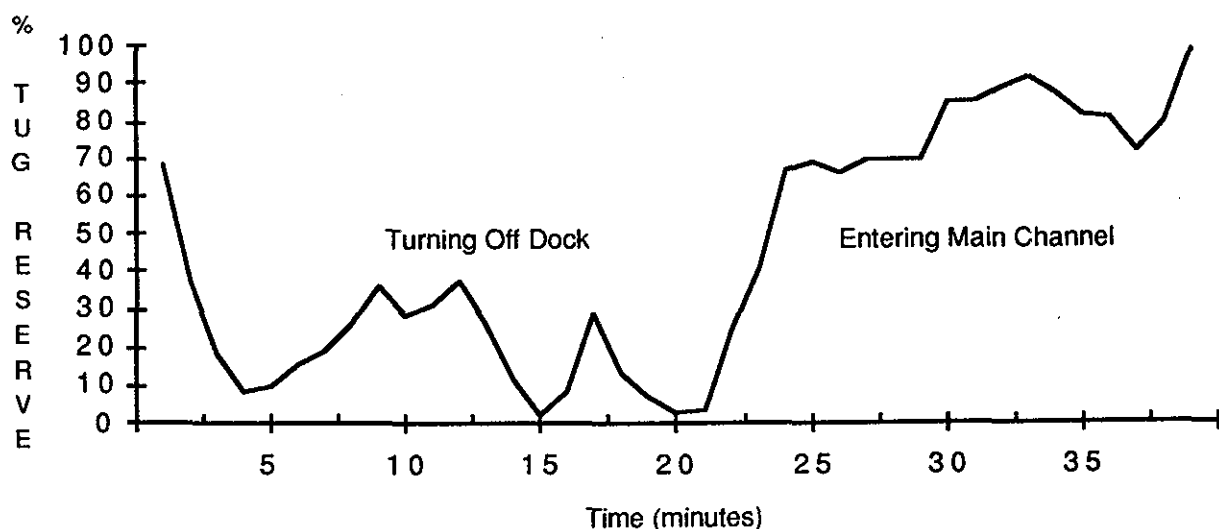


FIGURE 18 Tug Reserve Control - Scenario 416
(mean values, all pilots)

tugs were used full out to decrease the time required to turn the vessel and, therefore, the low TRC is not an indication of a difficult or unsafe condition

The two pilots who maintained good position through the turn under the bridge ended up crossing into the 35' MLW section of the main channel. Although this did not represent a grounding hazard in this scenario, it would be a potential hazard for the containership turning during the maximum ebb tide when the water level is lower. Although this was not simulated, based on results in the Reserved Channel, the pilots would most likely be able to execute a tighter turn during the ebb tide since the force of the current would tend to assist the vessel in the turn. If Plan 2 is not implemented, additional simulations should be conducted to verify this assumption.

4.2 CHELSEA RIVER

The simulation of the Chelsea River improvements included the portion of the Main Ship Channel north of Pier 10, the Inner Confluence Area, and the Chelsea River to the turning basin above the Gulf Oil facility. Two bridges crossing the Chelsea River present potential navigation problem areas in this reach. The McArdle Bridge, located in the bend where the Chelsea River meets the Inner Confluence, has a horizontal clearance of 175' (which does not restrict the beam of ships in the lower reach of the river), however, pilots prefer that vessels not exceed 106' in beam and 630' in length due to the curvature of the channel and presence of the bridge in this reach. The Chelsea Street Bridge has a horizontal clearance of 96' and limits the beam of vessels that can transit the upper reach. There currently is a beam restriction at the bridge of 90.5' during the day and 85.5' at night. Local pilots have expressed concern for vessel safety during the upstream and downstream approaches to both bridges.

The Chelsea River was simulated using two different vessels. A larger ship (50K Tanker) will be used to transit the lower reach from the Main Ship Channel to the Chelsea Street Bridge and to examine the approaches to the McArdle Bridge. A smaller ship (41K Tanker) was used to transit the upper reach, to examine the approaches to the Chelsea Street Bridge and to test turning operations in the turning basin.

4.2.1 Scenario 417 vs. 418

Scenario 417 tested the existing lower reach of the Chelsea river with a 50K DWT tanker loaded to 38'. The test started with the vessel in the Main Ship Channel, then turning and proceeding through the McArdle Bridge, then transiting the lower reach and preparing to dock at Mobil. In Scenario 418, the planned channel (deepened to 38' MLW plus 6' tide) was tested with the vessel loaded to 42'. Both scenarios were run with a maximum flood tidal current.

The main findings and conclusions derived from the comparison of performance seen in the planned vs. the existing channel configurations and depths are as follows:

Due to the relatively large size of the test vessel, safety was marginal in both the existing and planned channels. It is anticipated that the deepening project will benefit ships with smaller overall dimensions and that vessels similar to the test vessel (50K DWT, 692' X 106, 42' draft) would represent the absolute largest vessel that could make this transit.

Two areas along the lower reach should be widened in conjunction with the deepening to insure adequate safety for deeply laden tankers. The areas that should be widened are; just inside the McArdle bridge to the south, and the south side of the channel before and through the turn at the Mobil Terminal. These areas are displayed in Figure 20A.

Discussion

The consensus among the pilots was that the simulation of the existing conditions represented a worst case scenario with respect to the vessel dimensions as they relate to the McArdle Bridge and channel dimensions. Several pilots gave less than "Adequate" safety ratings for certain phases of the maneuver, as seen in Figure 19. This can be attributed to the fact that it is not common for a vessel of this size to transit the river in the real world. The majority of vessels that now make this transit are smaller in size, although vessels approaching the dimensions of the test vessel have made this transit on rare occasions. The majority of pilots basically believed that this scenario was marginal in terms of safety, and that the test vessel represented the largest vessel that could possibly accomplish this maneuver.

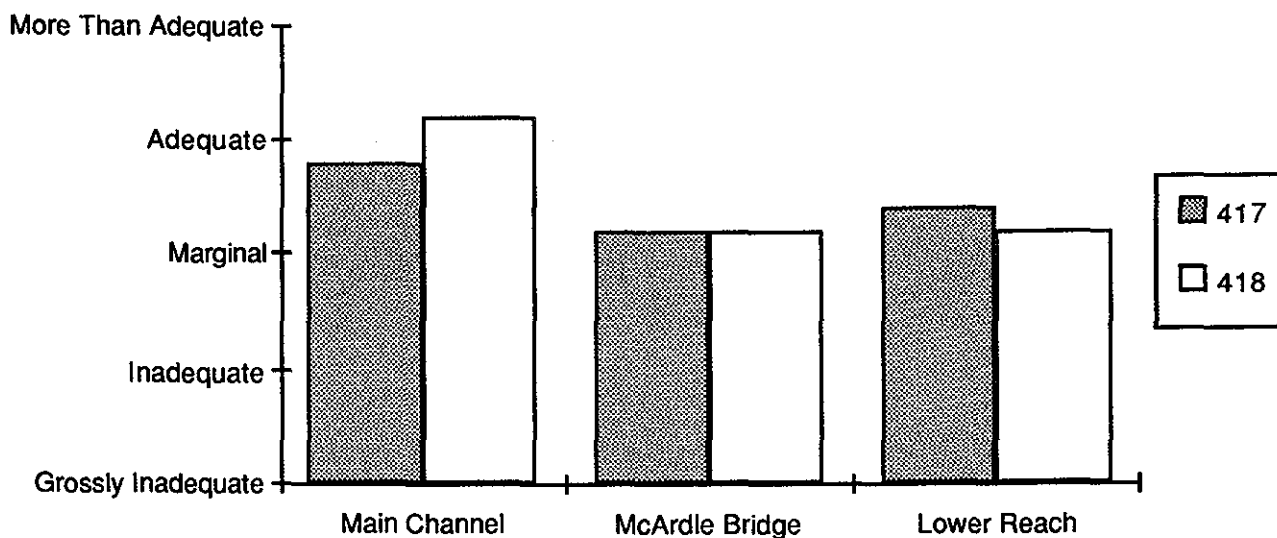


FIGURE 19 Pilot Evaluation - Margin Of Safety - Scenarios 417/418
(mean values, all pilots)

The track plots for the existing run indicated that all pilots were able to transit the McArdle Bridge without touching the bridge fendering system. It was observed that the vessel plots in the lower reach of the river showed all pilots crossing over the south side of the Federal channel boundary immediately inbound of the McArdle Bridge. When asked about these channel excursions, the pilots mentioned that their track plots were representative of actual transits in the Chelsea River and that the existing conditions in the river allow for such a position. They also mentioned that this position is required for them to safely accomplish the maneuver.

Another area on the track plots that showed routine channel excursions was the south side boundary in the turn before the Mobil terminal. As the vessel initiated this turn, the swept path (area of water swept by the ship) along the channel axis increased causing the stern to exceed the boundary. Again, the pilots believed these plots corresponded to actual vessel paths. A trackplot showing a representative transit appears in Figure 20.

Note that in the real world, present draft limitations imposed by Mobil cause vessels calling on this terminal to come into the lower reach at lighter drafts than were simulated. This results in the vessels being able to navigate safely outside of the Federal channel in certain areas. However, when the deepening project is completed, vessels will have increased drafts and will therefore be required to stay within the Federal channel boundaries to avoid a potential grounding hazard.

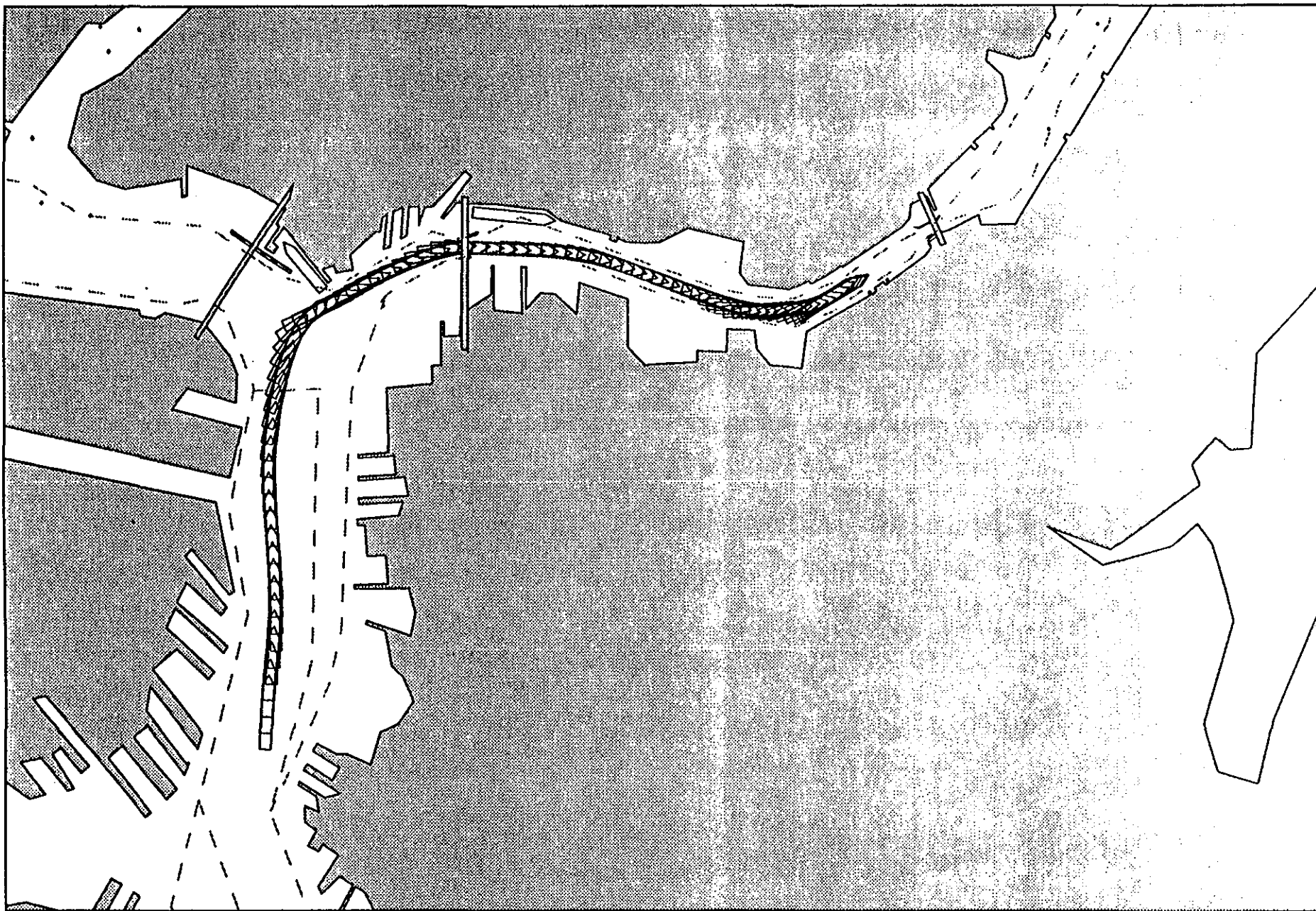


FIGURE 20 Individual Trackplot - Scenario 417 - Existing - 50K Tanker

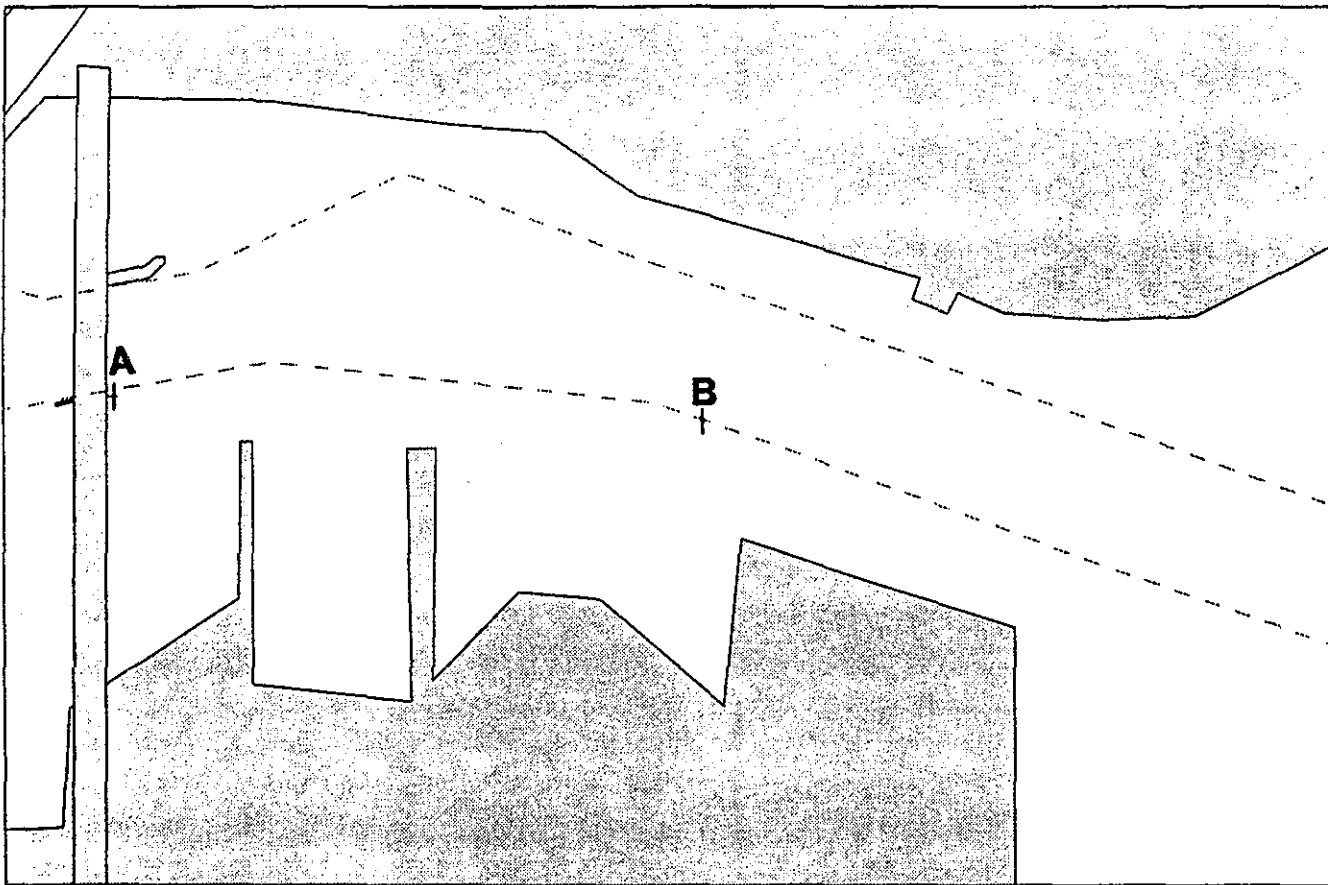
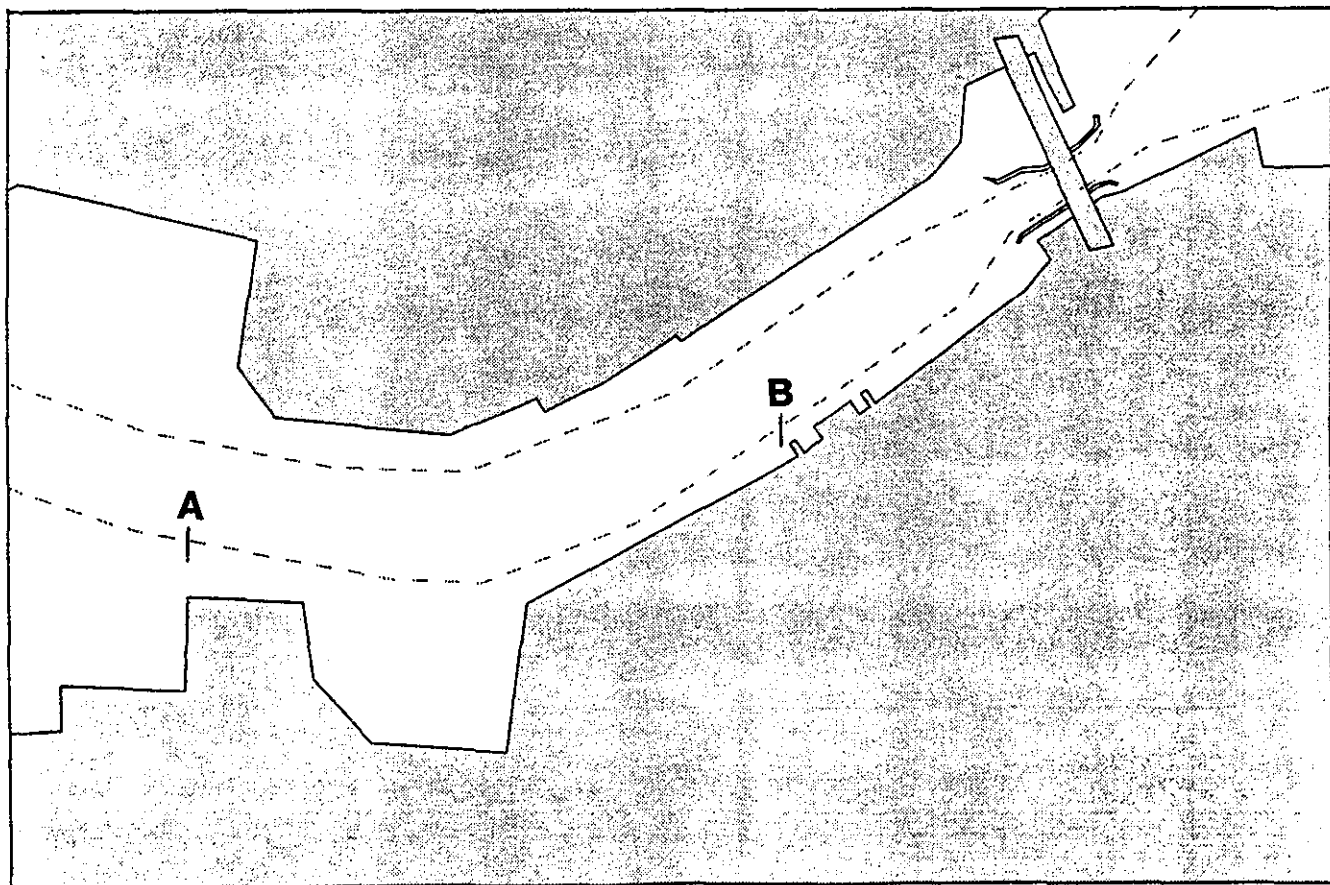


FIGURE 20A Areas between A and B require widening



The pilots gave lower safety ratings for the planned scenario with the 50K DWT at a 42' draft. Four out of five pilots gave ratings of "Marginal" to "Inadequate" for the bridge passage and the transit of the lower reach of the river. This decrease in safety rating can be attributed to the increased mass of the vessel.

The track plots showed vessel positions very similar to the existing maneuver with all pilots successfully negotiating the McArdle Bridge passage and generally exceeding the Federal channel in the same locations along the lower reach. One vessel track plot indicated an overshoot of the terminal which would have probably resulted in the vessel grounding at the bow, very close to the Chelsea Street Bridge south fender.

One pilot mentioned that it was difficult to decrease the headway of the vessel due to its large mass. The same pilot noted that a vessel of this size going to the Mobil terminal would eventually have to back all the way out into the Inner Confluence upon departure. Any large vessel that currently calls on the Mobil terminal, but cannot make its way to the upper turning basin, must currently be backed out, in a ballasted condition, to the Inner Confluence. If larger vessels are to be used, additional simulations of this scenario should be considered.

Measurement of the SRC and TRC indicated that there was sufficient control force in reserve for the planned maneuver. However, due to the tight tolerances involved in the narrow channel and bridge passage, vessel proximity (as seen in the trackplots) most accurately reflects the safety of the maneuvers in the Chelsea river. In other words, adding more tugs to this maneuver would not necessarily make the maneuver any safer. A plot comparing TRC of tests in the existing and planned designs is shown in Figure 21.

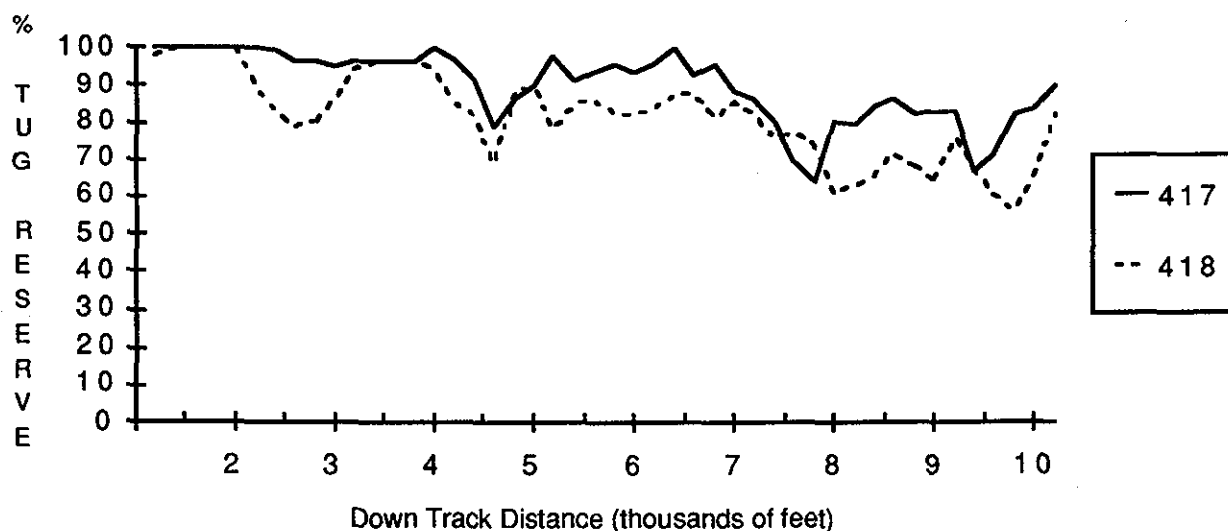


FIGURE 21 Tug Reserve Control - Scenarios 417/418
(mean values, all pilots)

4.2.2 Scenarios 419 vs. 420

Scenarios 419 and 420 tested the upper reach of the Chelsea River with a 41K DWT tanker on a flood tide with a tidal height of 6' above MLW. The tanker started in the middle of the lower reach, transited through the Chelsea Street Bridge, turned in the turning basin and prepared to dock at the Gulf terminal. In the existing design, the vessel was loaded to 38' and transited the 35' MLW

channel on the flood tide. In the planned design, the vessel was loaded to 42' and the channel had a depth of 38' MLW. The proposed replacement bridge fendering system for the Chelsea Street Bridge was modeled for the planned configuration.

The main findings and conclusions derived from the comparison of performance seen in the planned vs. the existing channel configurations and depths are as follows:

In the planned design, using the 41K tanker, the Chelsea Street Bridge transits were accomplished with a minimal margin of safety. Transit of the upper reach was accomplished with an adequate margin of safety. Smaller vessels, such as those being presently used in this area, would be able to load deeper and transit safely. The full benefit of the deepening project may only be achievable by widening the channel under a new Chelsea Street Bridge.

Extending the Federal channel from fender to fender at the Chelsea Street Bridge, is an important feature.

Discussion

The pilots' safety rating was generally "Adequate" for all phases of the existing maneuver as seen in Figure 22. The track plots indicated that the pilots were able to maintain vessel position within the Federal channel during the turn before the Chelsea Street Bridge, however, the stern of the vessel skirted the south channel boundary during several tests. The vessel's position was kept close to the Chelsea side fender when transiting the Chelsea Street Bridge, which is their normal strategy (due to the bridge overhang on East Boston side). Some pilots slightly rubbed up against the fender, which probably would not have resulted in any damage.

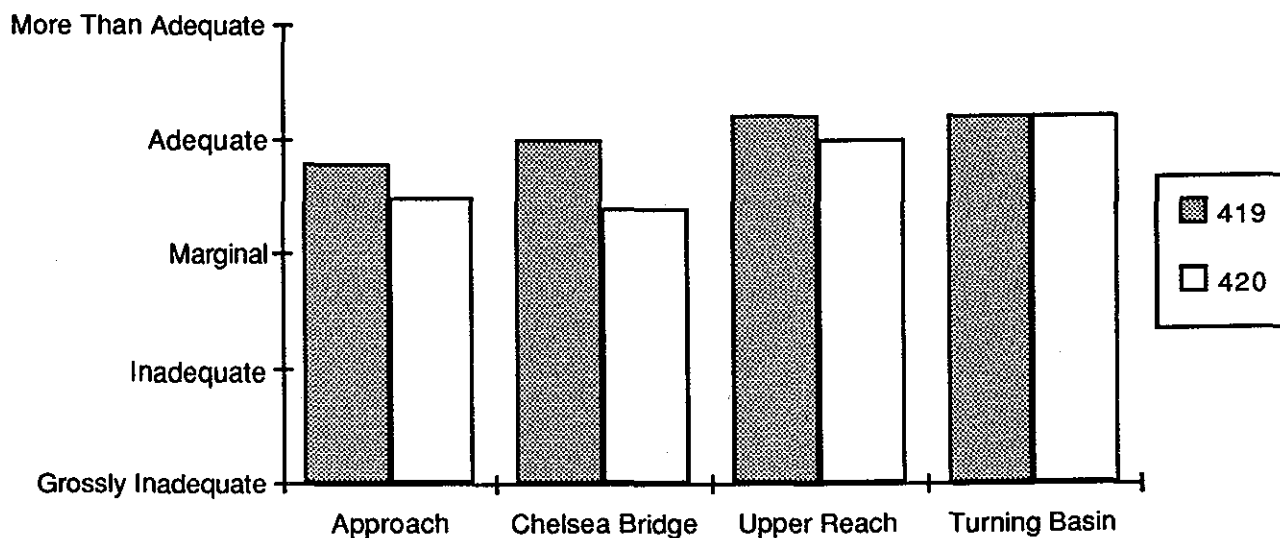


FIGURE 22 Pilot Evaluation - Margin Of Safety - Scenarios 419/420
(mean values, all pilots)

Two pilots noted that the bank cushion, which causes the bow of the vessel to swing to the right just before the bridge, was weaker on the simulator. This bank was tuned during the pilot validation phase, but apparently the force of the resulting cushion was not as great as they anticipated. The pilots' comments on the validity of the simulated bridge passage was mixed, ranging from "tremendous" to "not realistic". This is due to the tight tolerances involved in this aspect of the

simulation coupled with the complex hydrodynamics that occur in the real world as the vessel displaces a large percentage of the water in the narrow waterway. Essentially, the simulation of the Chelsea bridge passage was pushing the envelope of the present simulation technology.

The pilots gave lower safety ratings for the approach and passage through the Chelsea Street Bridge in the planned scenario with the 41K DWT loaded to 42'. The average rating was only slightly above "Marginal". This is attributed to the increased mass of the vessel and the perceived decrease in channel opening between the proposed bridge fenders. The existing opening through the bridge is approximately 115' at the surface and approximately 96' at the base due to the fenders being pushed and toed out over the years. The proposed fendering system will be vertical and thus only allow a horizontal clearance of 96' from the bottom to the surface, giving the impression of a smaller opening. Since the simulated vessel has a beam of 90', there was only a 6' tolerance when transiting the bridge. A representative transit is shown in Figure 23A, a blow-up view of the bridge passage is shown in Figure 23B.

The smaller safety margins recorded during transits through the planned design and feedback from the pilots provide strong evidence that the present vessels are the largest vessels that can safely transit through the Chelsea Street Bridge and that, in the planned configuration, the bridge represents a bottleneck situation. The new fendering system, although needed to protect the bridge and vessel from damage, brings the total clearance down to 6' and results in less than adequate safety for a 41K DWT tanker at 42'. Therefore, the benefit of the deepening project may not be fully realized due to the limiting factor of the Chelsea Street Bridge. This supports the U. S. Coast Guard's proposal to replace the Chelsea Street Bridge with a vertical lift bridge having a considerably wider horizontal clearance.

If this new bridge is implemented, an adequate safety level would probably be achieved with a vessel similar to the test vessel, although this situation was not tested. One pilot expressed the concern that with a new bridge in place, economic pressures will force vessels larger than the test vessel to transit the upper reach of the Chelsea River. He believed that this would create a situation with a marginal or inadequate level of safety due to the restrictive channel dimensions. If the bridge is replaced, additional simulation should be conducted to determine the safety of larger vessels transiting the waterway.

In the upper reach, average safety rating was "Adequate" indicating that the pilots do not anticipate any problems with the more deeply laden vessel in these areas. The track plots of these areas were very similar to those of the existing scenario indicating no deterioration in performance due to the increased displacement in the deepened channels.

As was the case in the lower reach, the levels of SRC and TRC in the upper reach indicated that there was an adequate level of reserve during the maneuver in the planned design. However, due to the tight tolerances involved in the narrow channel and bridge passage, vessel proximity, and not reserve control, most accurately reflects the safety of the maneuvers in the Chelsea river.

4.3 RESERVED CHANNEL

The simulation of the Reserved Channel improvements included portions of the Main Ship Channel from the second turn inbound to the Reserved Channel, and the Reserved Channel. The 87K Tanker and Panamax container ship were used to test the improvements.

4.3.1 Scenarios 421 vs. 422

Inbound runs into the Reserved Channel with a 87K DWT tanker on the flood tide were tested in Scenarios 421 and 422 which were the existing and planned conditions respectively. A ship draft of 38' was used for the existing condition (421), which allowed safe navigation in both sides of the

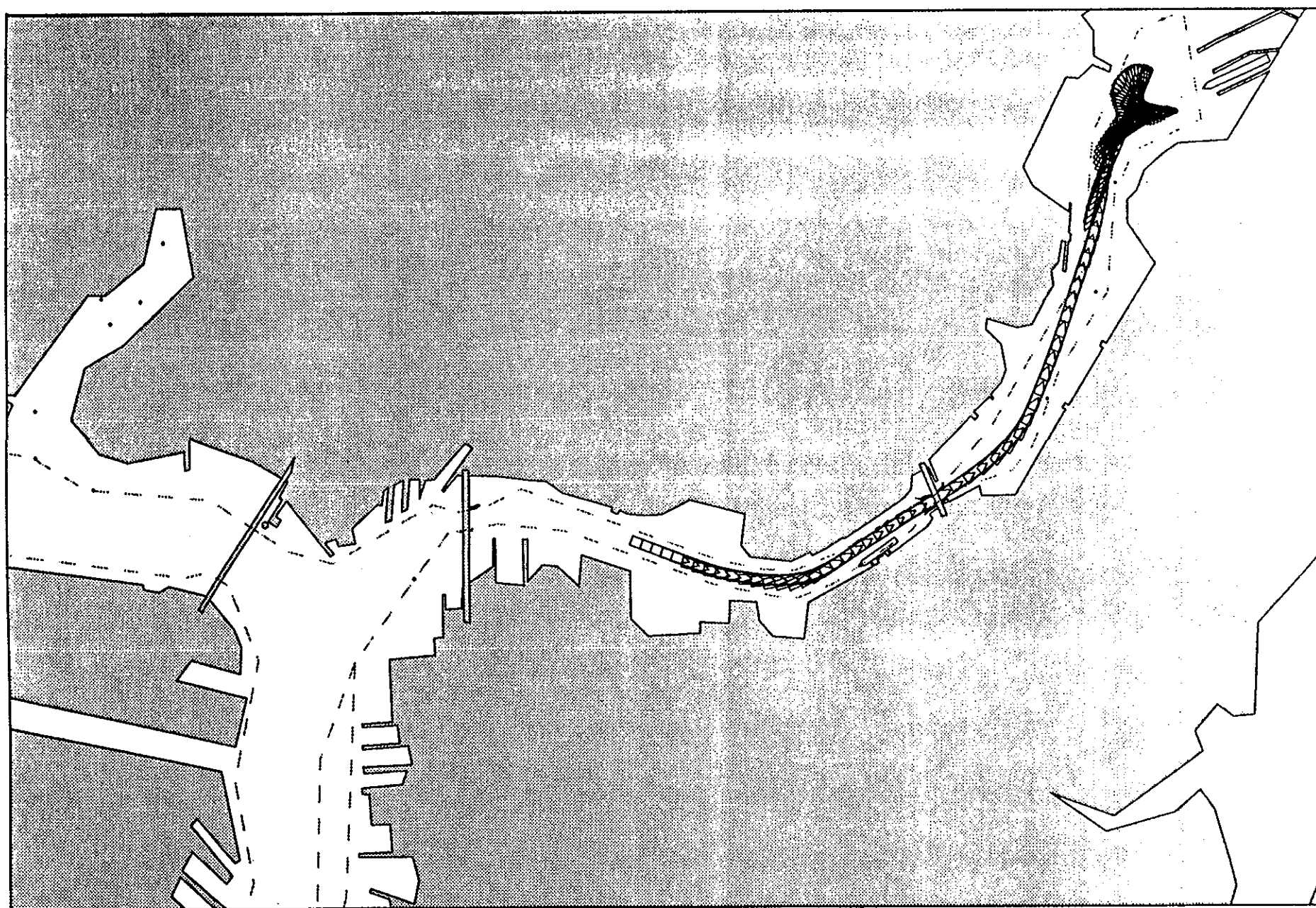


FIGURE 23A Individual Trackplot - Scenario 420 - Planned - 41K Tanker

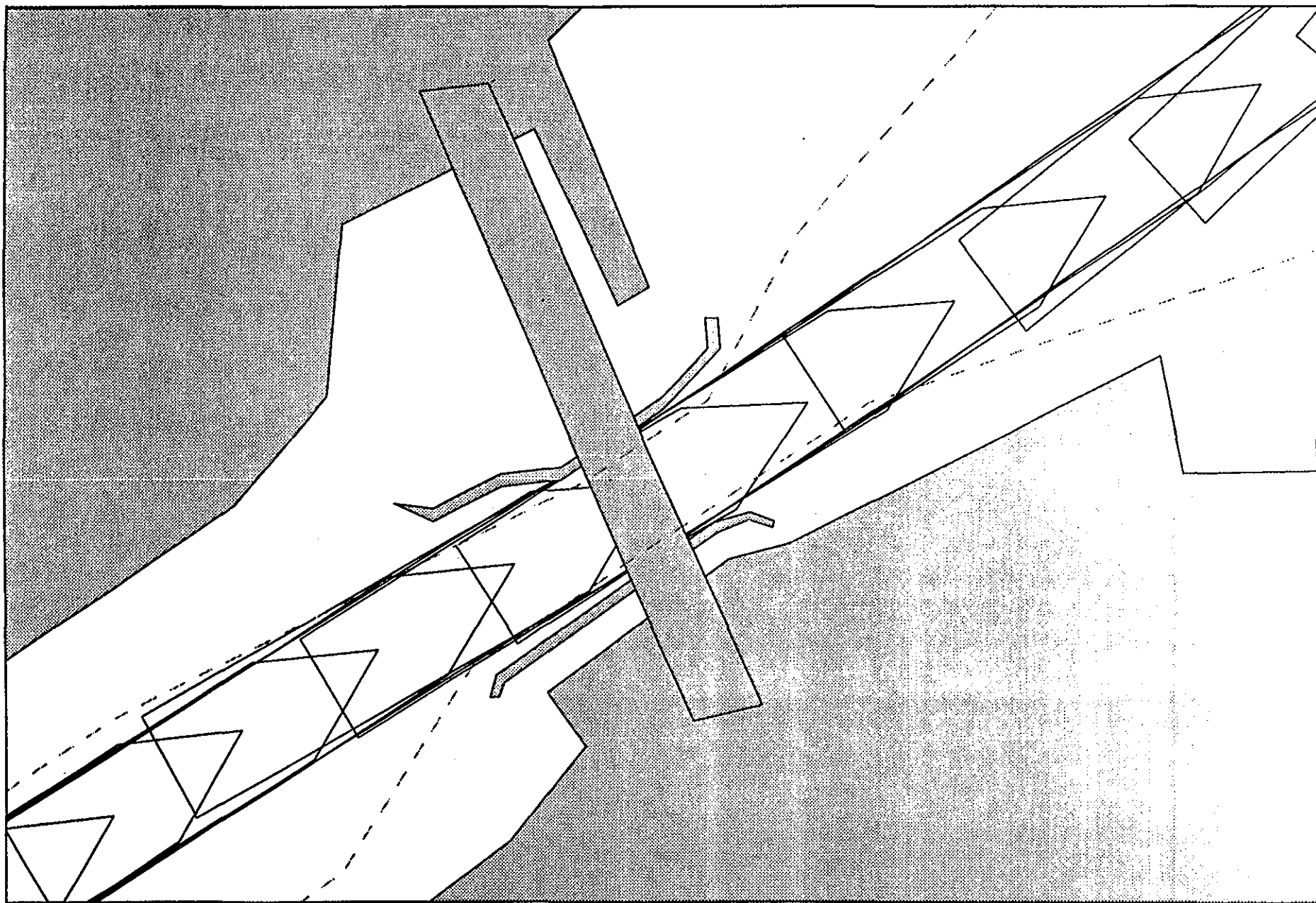


FIGURE 23B Detail of Chelsea Street Bridge Transit

Main Ship Channel as well as the Reserved Channel. The maneuver consisted of transiting the Main Ship Channel, turning the vessel in the Main Ship Channel, backing into the Reserved Channel, and preparing to dock at the Coastal terminal. A ship draft of 45' was used to test the planned configuration shown in Figure 3C. Due to the deep draft of the vessel, the 35' MLW section of the Main Ship Channel was off limits, since it represented a potential grounding risk.

The main findings and conclusions derived from the comparison of performance seen in the planned vs. the existing channel configurations and depths are as follows:

The proposed design provides adequate safety for this maneuver.

The 40' MLW area off the Massport Pier should be included in the Federal project based on performance seen during tests in both existing and planned channel designs.

The 40' MLW notch area in the Main Ship Channel was not utilized.

Safety ratings of "Adequate" to "More than Adequate" was the norm for the maneuver in the existing design with the 87K DWT at 38'. The pilots noted having difficulty bringing the bow around into the flood tide, which is not normally the case in the real world, and, therefore, felt that the scenario represented an extreme with regard to current. As a result of the struggle of bringing the bow around, three of the vessels drifted with the flood current, and crossed into the unmaintained area off the Massport Pier. It is important to note, however, that ships seldom come into the Reserved Channel loaded deeper than 36'.

Because there is naturally deep water in the area, pilots routinely cross over the corner of the Federal channel where the northern boundary of the Reserved Channel meets the Main Ship Channel. However, with a 38' draft and +6' tidal height, there would be insufficient depth approximately 950' off the Massport Pier along the northern channel boundary of the Reserved Channel (latest survey May, 1990). With maximum ordinary drafts of 36', which the pilots are accustomed to, there would be adequate depth until the vessel was 300' off the Massport Pier along the northern boundary. The pilots indicated that the problem of the vessel drifting into the unmaintained area off the Massport Pier, due to the vessel being broad side to the flood current, is a constant concern to the pilots in real world operations.

Many of the pilots noted that if given another opportunity to perform the simulated test, they would have turned earlier to keep the vessel closer to the moored ship at Castle Island berth 16. The pilots also noted that having a vessel at berth 16, which is very often the case, definitely makes the maneuver more difficult because it forces the pilot to keep the vessel farther to the northeast than is desirable. This situation, when combined with the already conservative current conditions and 38' vessel draft, obviously represented a "worst case" scenario.

During the tests in the planned channel design, 4 of 5 pilots were able to keep the vessel within the Federal channels, which is an improvement over the performance seen in the tests of the existing design. Since the area off the Massport Pier was accessible, the maneuver was executed in a manner that was considerably different from that used in the existing design. The majority of the turn was completed outside the Main Ship Channel resulting in the vessel being less affected by the currents. The pilots' gave an average safety rating of "Adequate" which indicated that the pilots felt that there was no degradation in safety compared to the existing design. All of the pilots took advantage of the dredged area off the Massport Pier but did not utilize the notched area in the Main Ship Channel. Composite trackplots showing all tests in the existing and planned designs are shown in Figures 24 and 25 respectively.

Several pilots indicated that additional tug assistance would be helpful in accomplishing this maneuver. Some pilots moved the starboard bow tug to the port bow to help push the bow down against the flood tide. This is not a standard practice since it leaves no tug on the starboard side to

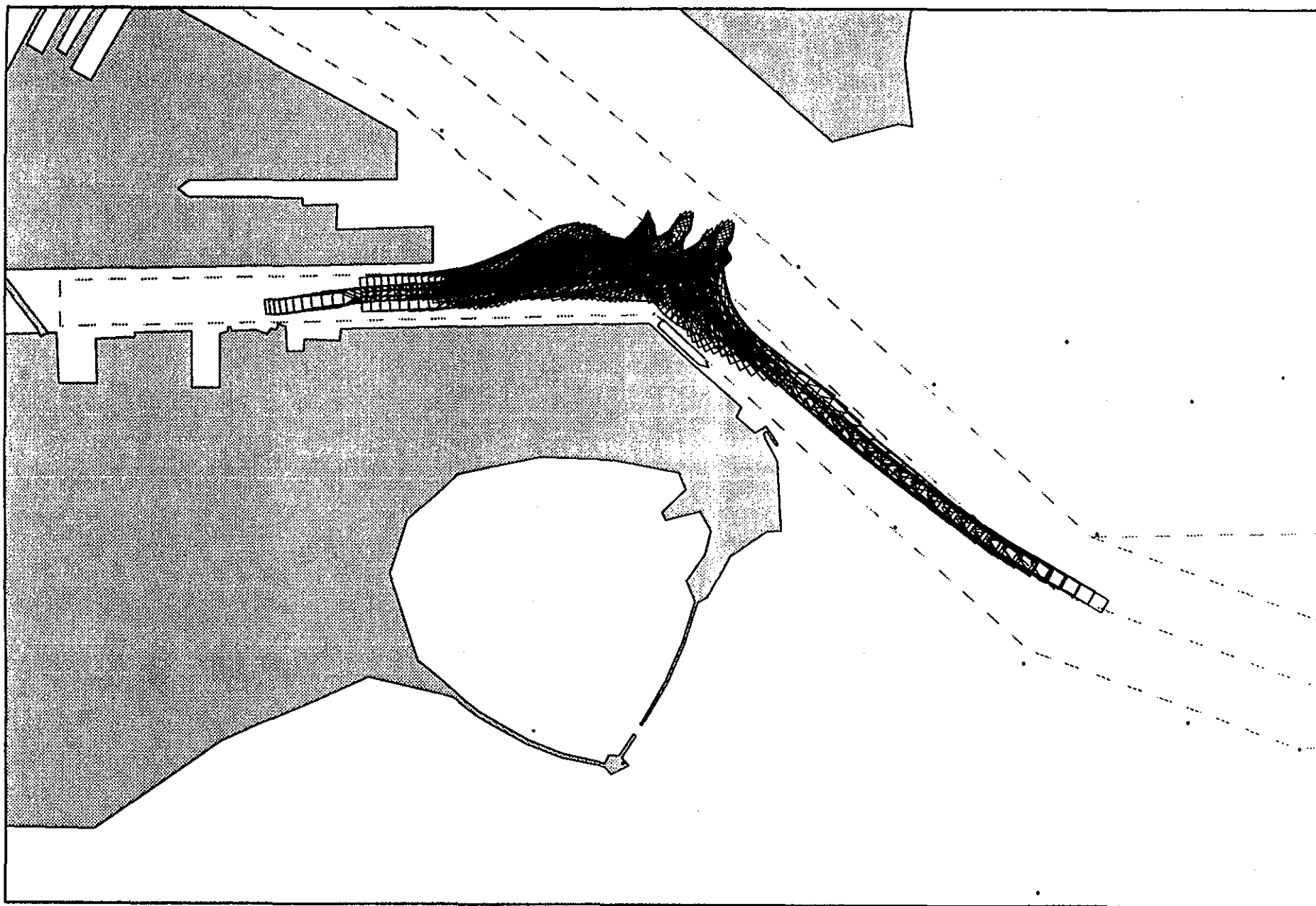


FIGURE 24 Composite Trackplot - Scenario 421 - Existing - 87K Tanker

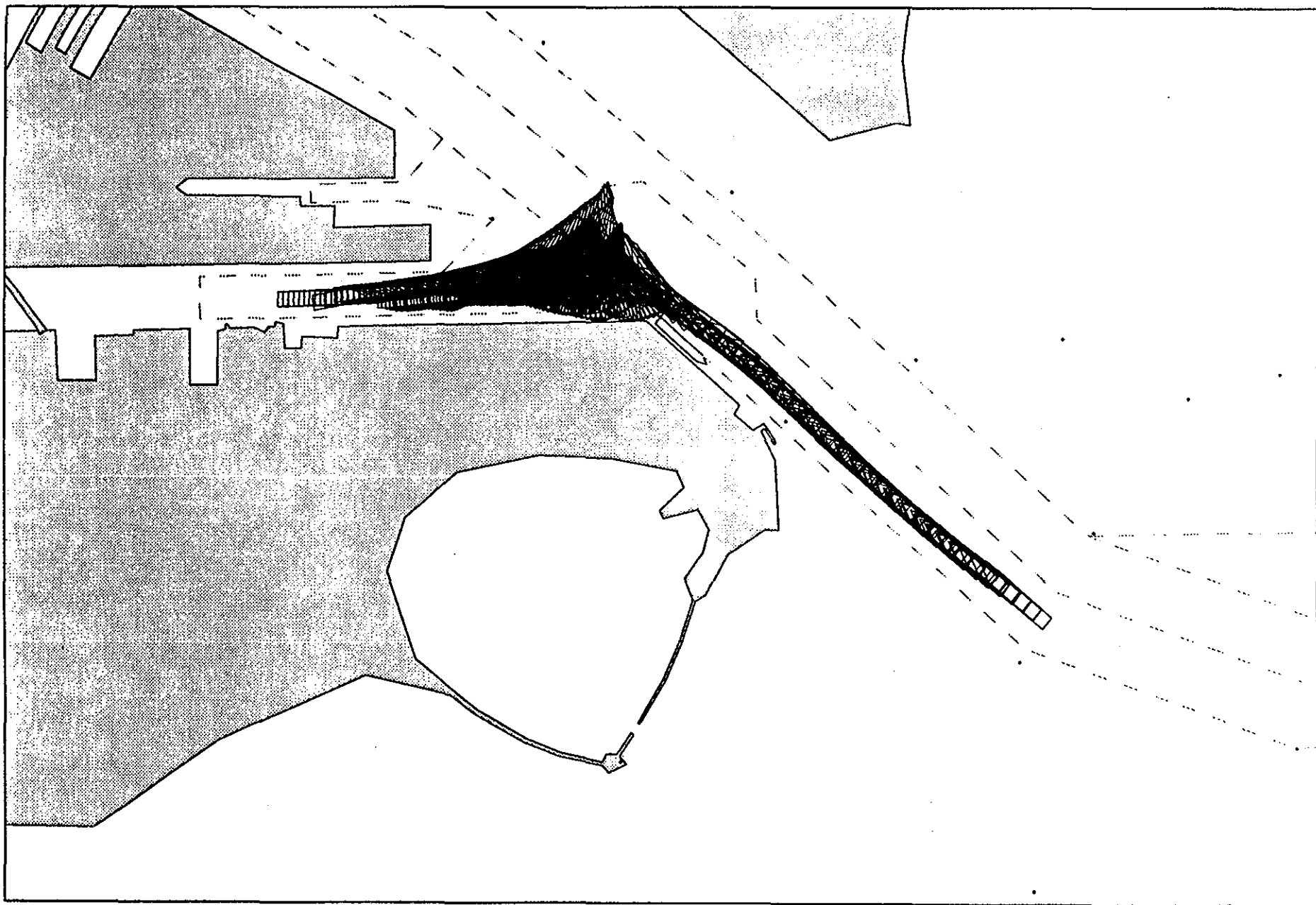


FIGURE 25 Composite Trackplot - Scenario 422 - Planned - 87K Tanker

check the swing of the vessel once it starts turning. In actual operations they would most likely ask for another tug boat on a job similar to the one tested. A plot of TRC vs. down track location shows this heavy use of tug assistance, see Figure 26. Note that the average TRC drops down to 25% in the turning area.

Several pilots indicated that the proposed aid to navigation scheme does not mark the limits of the proposed notch and no longer provides a marker at the end of the Reserved Channel as does the present buoy R "10". The pilots also indicated that the lighted buoy off of the Massport Pier was very valuable and recommended that it be implemented to help mark the proposed maneuvering area.



FIGURE 26 Tug Reserve Control - Scenarios 421/422
(mean values, all pilots)

4.3.2 Scenarios 423 vs. 424 & 424A

A Panamax container vessel was used to test inbound transits into the Reserved Channel on an ebb tide in the existing design during Scenario 423. The maneuver consisted of transiting the Main Ship Channel, turning the vessel in the Main Ship Channel, backing into the Reserved Channel, and preparing to dock at the Castle Island terminal. The vessel had a draft of 36', which allowed the pilots to fully utilize the entire Main Ship Channel and Reserved Channel.

The vessel was loaded to 40' and the maneuver was repeated in the planned design in Scenario 424. Conditions tested included a tidal height of +2' above MLW and corresponding maximum ebb tide. The 35' MLW section of the Main Ship Channel was therefore too shallow for the test vessel. This forced the pilots to accomplish the maneuver using the dredged area off of the Massport Pier and the 40' MLW notch that extends half way into the 35' MLW side of the Main Ship Channel. All tests were conducted with a 10 knot North West wind.

The main findings and conclusions derived from the comparison of performance seen in the planned vs. the existing channel configurations and depths are as follows:

The 40' MLW notch in Main Ship Channel failed to provide maneuvering room for this vessel.

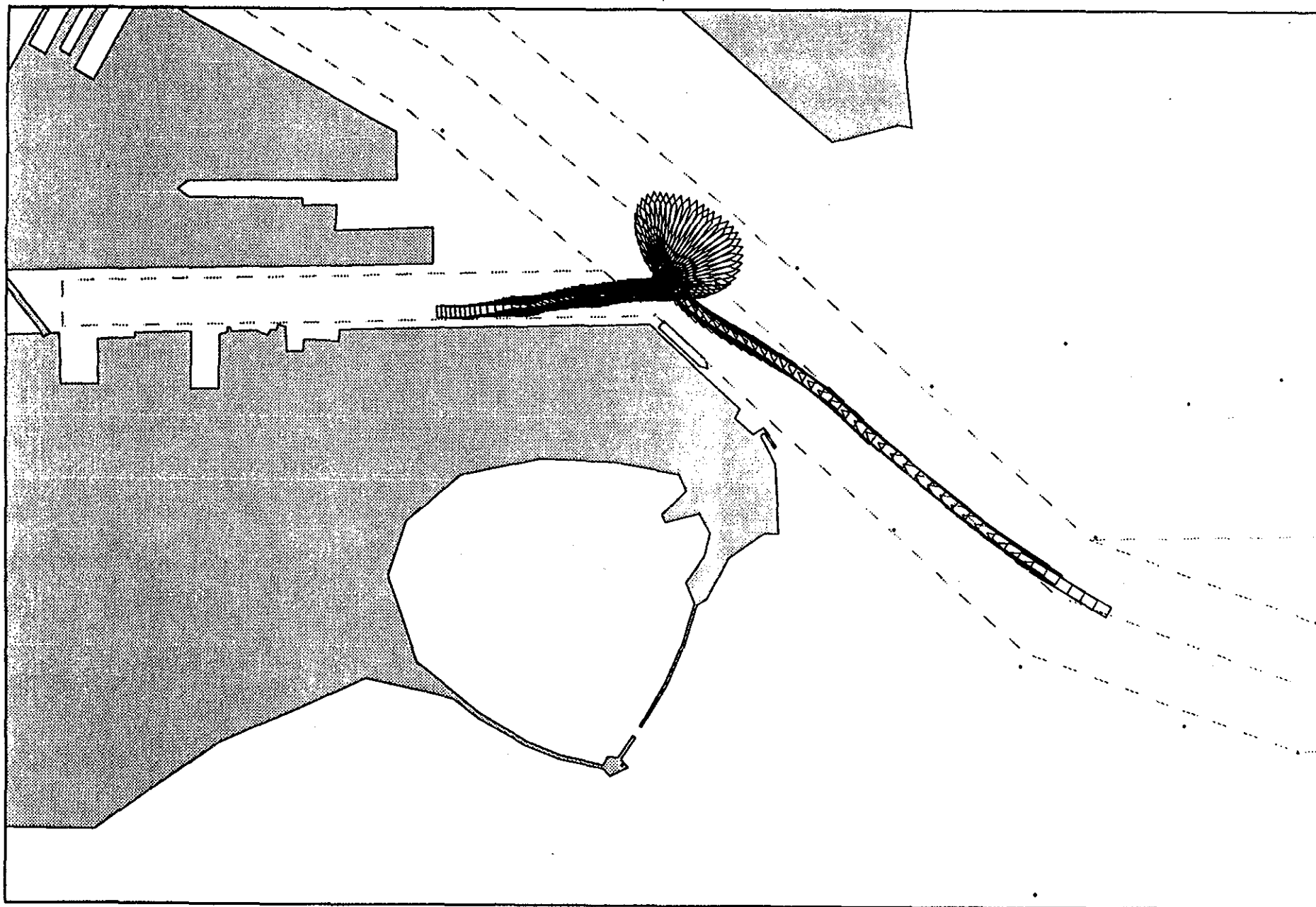


FIGURE 27 Individual Trackplot - Scenario 423 - Existing - Panamax

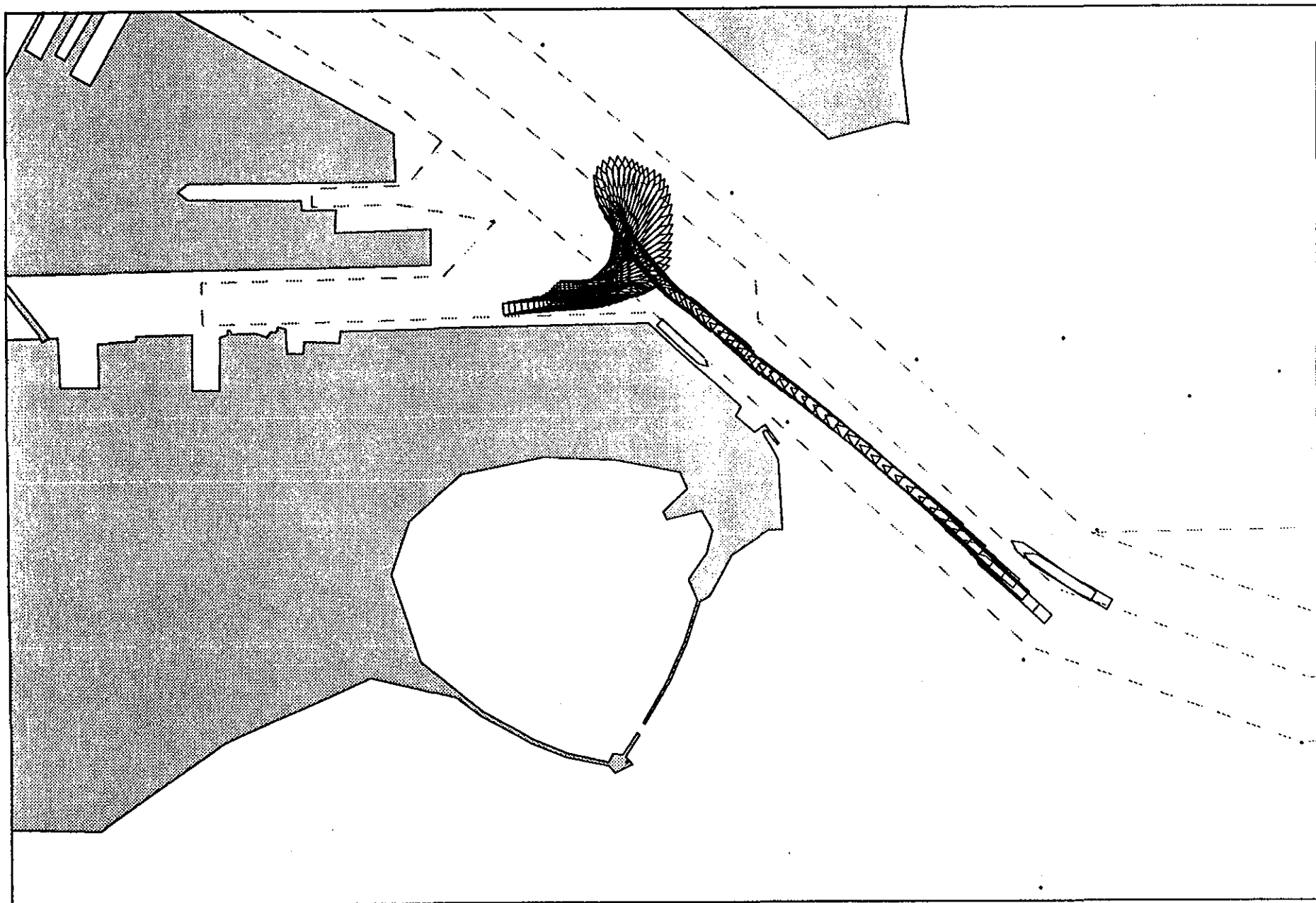


FIGURE 28 Individual Trackplot - Scenario 424 - Planned - Panamax

The 40' MLW area off the Massport Pier was utilized during successful maneuvers in the planned configuration.

Close analysis of data suggests that the planned design may be acceptable if the new strategy of maneuvering off the Massport Pier (as seen in Fig. 31) is employed by the pilots. Additional simulation testing is recommended to fine-tune the design and achieve a full test set of successful maneuvers.

The general consensus among the pilots after completing the existing scenario was that the combined force of the ebb current and northwest wind overwhelmed the tug boats. Turning at the point they normally do resulted in the ship falling downstream too far, and caused several pilots to use recovery maneuvers. For example, two pilots purposely let the bow fall all the way off and then backed the vessel up the Main Ship Channel and into the Reserved Channel. Another pilot purposely let the stern fall off and then proceeded farther up the main channel before initiating a second attempt at the turning maneuver. Those pilots who drove the ship further up the Main Ship Channel initially were able to accomplish the maneuver without resorting to recovery maneuvers. A representative example of the maneuver is shown in Figure 27.

A review of the track plots of the maneuver in the planned design clearly suggests that the design will not work if the pilots use their traditional strategy to turn the vessel. The problem is the length of the vessel relative to the available area. Initiating the turn when the entire vessel is inside the Main Ship Channel results in the bow of the vessel exceeding the limits of the 40' notch area since the maximum dimension of deep water in the Main Ship Channel is 900' (600' wide 40' MLW side of channel plus 300' wide notch) and the overall length of the test vessel is 950'. An example of this problem is shown Figure 28. The pilots indicated that the only way to successfully accomplish this maneuver within the 40' maneuvering area would be to drive the vessel into the dredged area off the Massport Pier before starting the turn.

The average safety rating for the turn maneuver in the planned configuration, shown in Figure 29, was below "Marginal" with four pilots exceeding the channel boundaries in the notched area. The pilots indicated that it was difficult to determine exactly where the notched area was due to lack of navigation aids. Note that it would be hard to mark the notch without impeding the transits of lighter draft traffic.

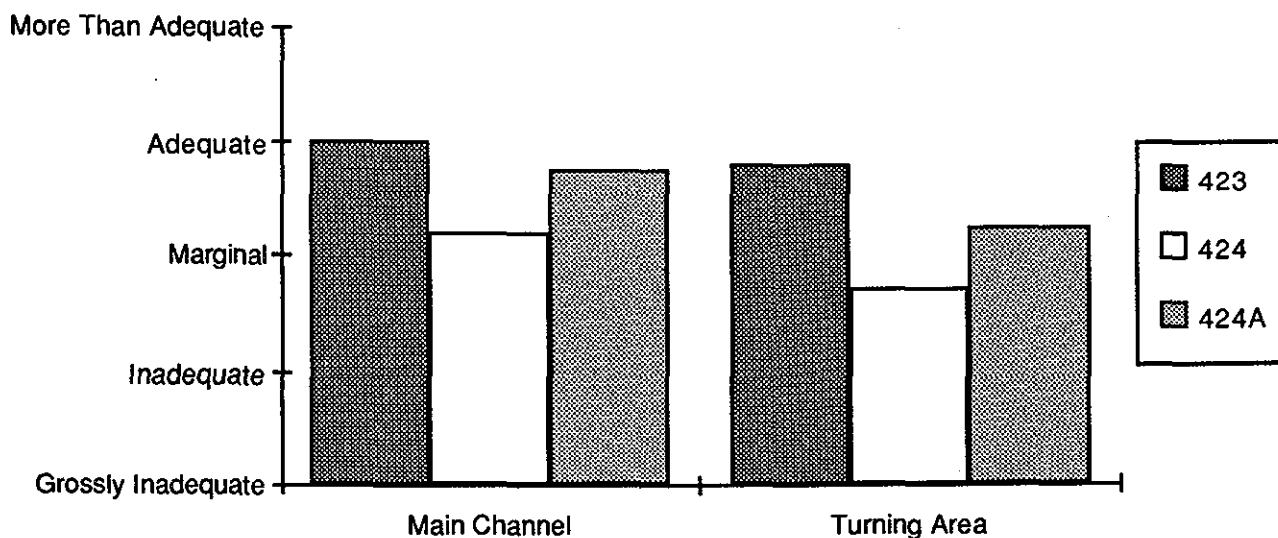


FIGURE 29 Pilot Evaluation - Margin Of Safety - Scenarios 423/424/424A
(mean values, all pilots, except 424A - 3 pilots)

As in the existing scenario, the pilots felt the environmental forces were extreme, and this required that the tugs be repositioned in a manner that was not consistent with present real world procedures. Most of the pilots said that additional tug horsepower would be required for this maneuver. Figure 30 shows the intensive use of tug support.

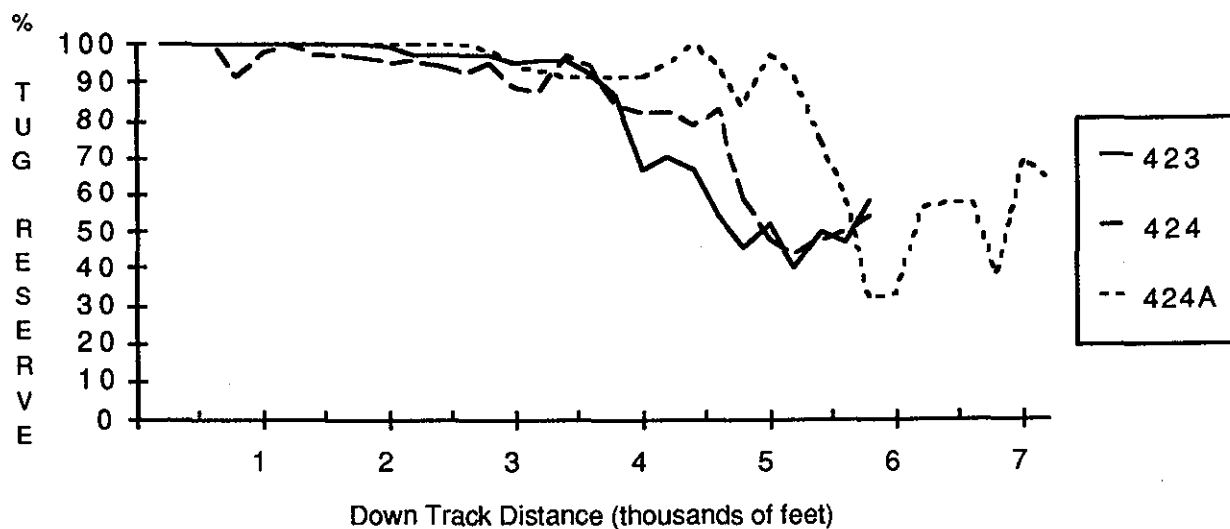


FIGURE 30 Tug Reserve Control - Scenarios 423/424/424A
(mean values, all pilots, except 424A - 3 pilots)

Since the results of the tests indicated that the traditional strategy, was not successful in the planned configuration, four of the five pilots were asked to repeat the test using the strategy they had suggested, i.e., placing the ship closer to the proposed buoy off the Massport Pier. Three of the pilots repeated the test using the new strategy, (Scenario 424A) and successfully accomplished the

turning maneuver inside the proposed Federal channel. The fourth pilot's approach was consistent with the new strategy, but he reverted to the existing strategy in the turn area resulting in vessel exceeding the channel boundary in the notched area. An example of the successful maneuver in the planned configuration using the alternative maneuvering strategy is shown in Figure 31.

Note that the three pilots who tried the new strategy, accomplished the turn maneuver without utilizing the notched area. In fact, the notched area was never used during any of the successful inbound tests in the planned design (tanker or Panamax container).

The pilots who tested the maneuver using the new strategy rated the safety of the turn higher than when they used the traditional strategy, however, the average (three pilots) rating was still only slightly higher than "Marginal". One reason for the lower than adequate rating may be the fact that the strategy is new and unfamiliar. One pilot commented: "This maneuver is perfectly feasible; it just takes a lot of getting used to. In view of the fact that this radically different maneuver has been realistically simulated at MSI, I would recommend each pilot do a couple of practice runs to get the feel for it."

Although all three pilots were successful in the turning phase of the maneuver, two of the pilots slightly crossed over into the 35' MLW section of the Main Ship Channel while trying to make a wide approach into the Massport Pier area. It was noted that it is helpful to the maneuver to take this turn as wide as possible, but it is difficult to determine where the 40'/35' transition is in the Main Ship Channel. A range on Spectacle Island would have been helpful for the pilots to better determine their position in the Main Ship Channel.

The pilots also recommended the use of more tug horsepower to counteract the strong wind and current, which is consistent with all the inbound Reserved Channel scenarios and consistent with the TRC values calculated.

4.3.3 Scenario 425 vs. 426

Outbound transits from the Reserved Channel were tested using the Panamax container vessel on the flood tide. The maneuver required the vessel to pull away from the berth (Castle Island 11), maneuver around another berthed container vessel and exit into the Main Ship Channel. The test vessel was loaded to 36' in the existing design (425) and 40' in the planned design (426). Due to the draft in relation to the tidal height, both sides of the Main Ship Channel were navigable even in the planned configuration. The area off the Massport Pier was only navigable in the planned configuration. A wind condition of 15 knots from the northwest was used.

The main findings and conclusions derived from the comparison of performance seen in the planned vs. the existing channel configurations and depths are as follows:

The planned configuration provides adequate safety for the conditions tested.

The 40' MLW notch in the Main Ship Channel was not utilized.

The 40' MLW area off Massport Pier was utilized.

Tests in the existing design were successfully completed by all pilots without any problems. Safety ratings by the pilots were all "Adequate" or above. The track plots show that all five pilots crossed over the northern boundary of the Reserved Channel where it meets the Main Ship Channel. As mentioned earlier, this is a common practice due to the naturally deep water in this area.

All five pilots accomplished the maneuver in the planned configuration with good clearance to all channel boundaries, as shown in Figure 32. Four of the pilots gave ratings from "Adequate" to "More than Adequate", but one pilot gave an "Inadequate" rating for the turn maneuver stating that

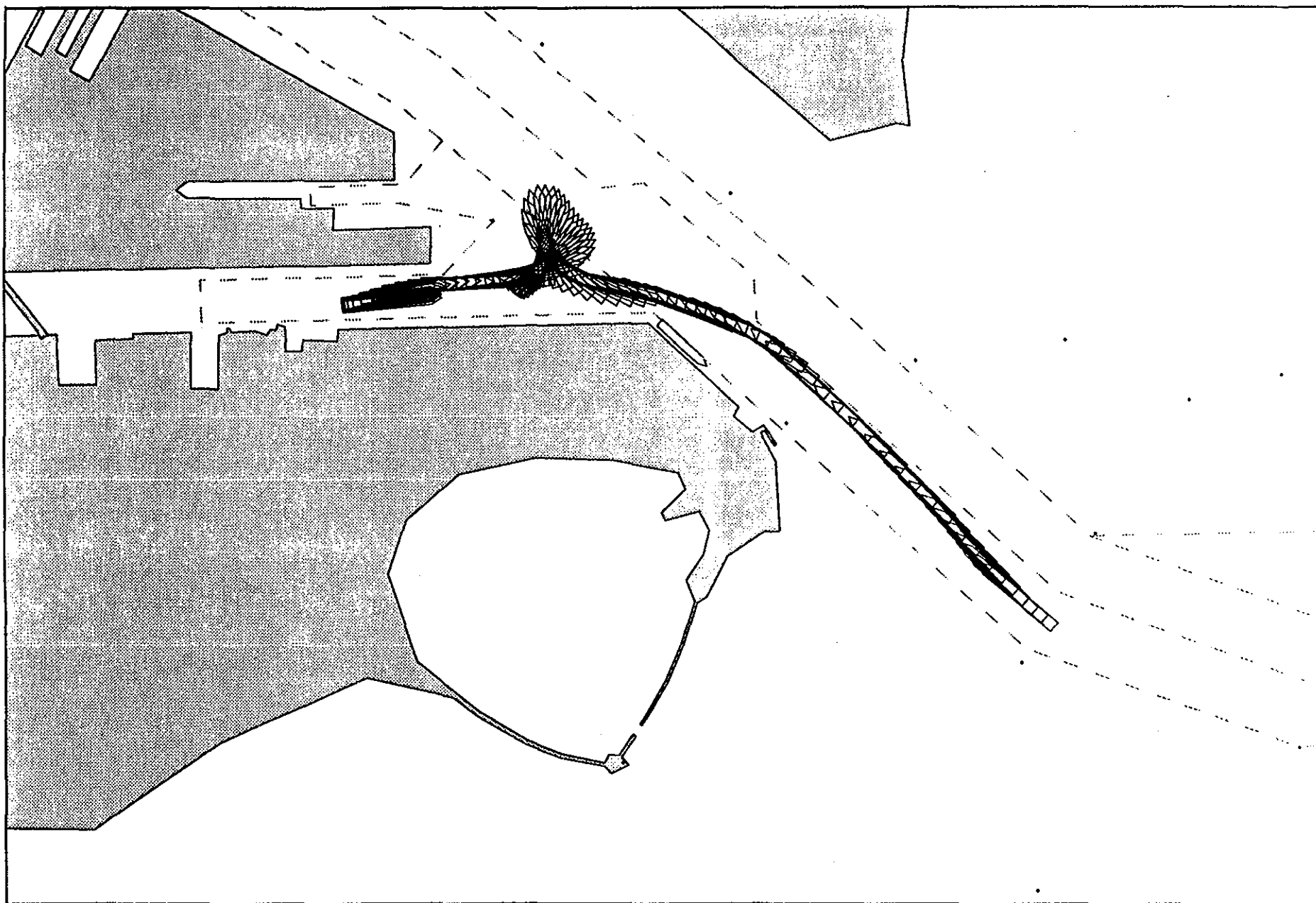


FIGURE 31 Individual Trackplot - Scenario 424A - Planned - Panamax

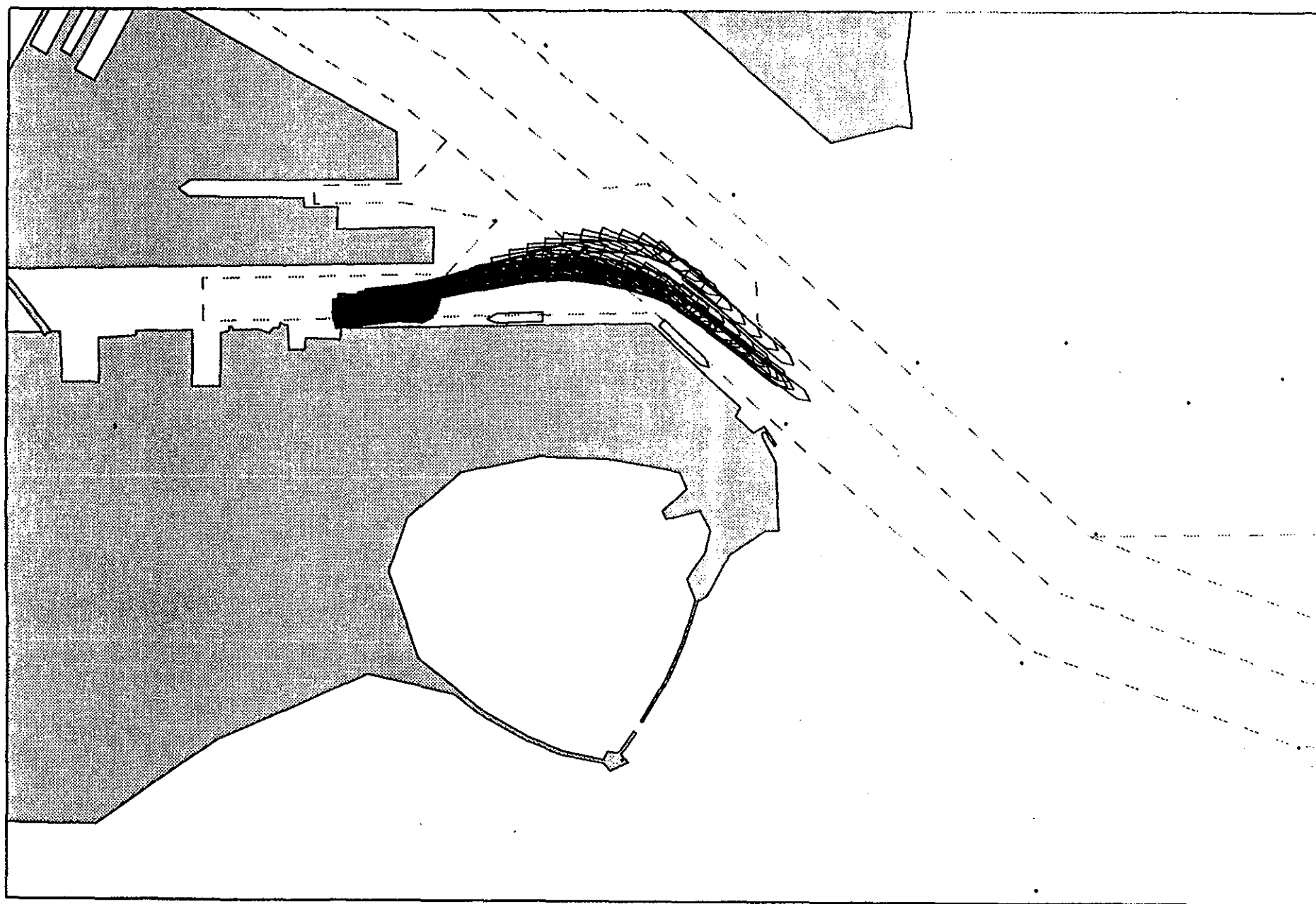


FIGURE 32 Composite Trackplot - Scenario 426 - Planned - Panamax

for deeper traffic, the 35' side of the Main Ship Channel would pose a potential grounding condition while making the turn out of Reserved Channel. Note that for this scenario there would have been 1' under keel clearance since the draft of the ship was 40' and the available water was 41' (35' MLW plus 6' tidal height). Since it is not anticipated that container ships would be loaded deeper than 40', and it would be extremely rare for a tanker to exit the Reserved Channel fully loaded this is not a concern, and the Scenarios 426 and 428 were indeed the maximum credible worst case situations that need to be considered.

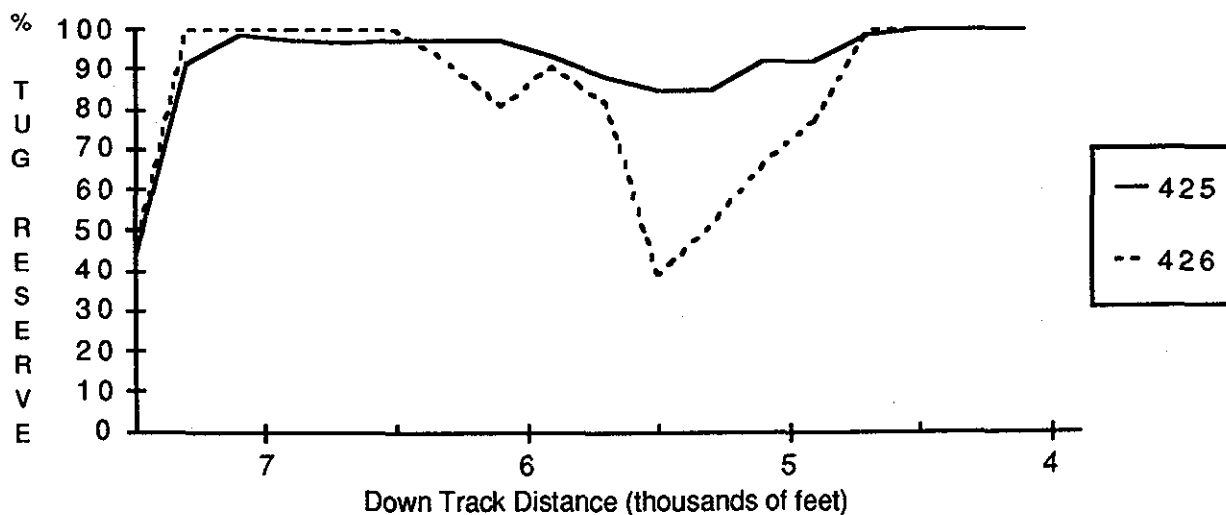
The TRC, shown in Figure 33, indicates that more tug support was required in the planned design, with tug usage peaking at 60% utilization. However, this high percent of tug usage was not maintained for a long period of time, the pilots did not consider this a problem and, therefore, the TRC is not indicative of a dangerous condition.

4.3.4 Scenario 427 vs. 428

Scenarios 427 and 428 repeated Scenarios 425 and 426 except that the outbound maneuver was done on the ebb tide instead of the flood. In the existing design (427), the vessel was able to safely maneuver in all sections of the Federal channel, while in the planned design (428) the vessel was constrained to the 40' MLW areas. Therefore, on the turn out of Reserved Channel, the pilots had to make a tight turn to keep the vessel on the 40' MLW side of the Main Ship Channel.

The main findings and conclusions derived from the comparison of performance seen in the planned vs. the existing channel configurations and depths are as follows:

The planned configuration appeared to provide adequate safety for the conditions tested but the pilots expressed concern about the turn maneuver.



**FIGURE 33 Tug Reserve Control - Scenarios 425/426
(mean values, all pilots)**

The 40' MLW notch in the Main Ship Channel was not utilized.

The 40' MLW area off the Massport Pier was utilized.

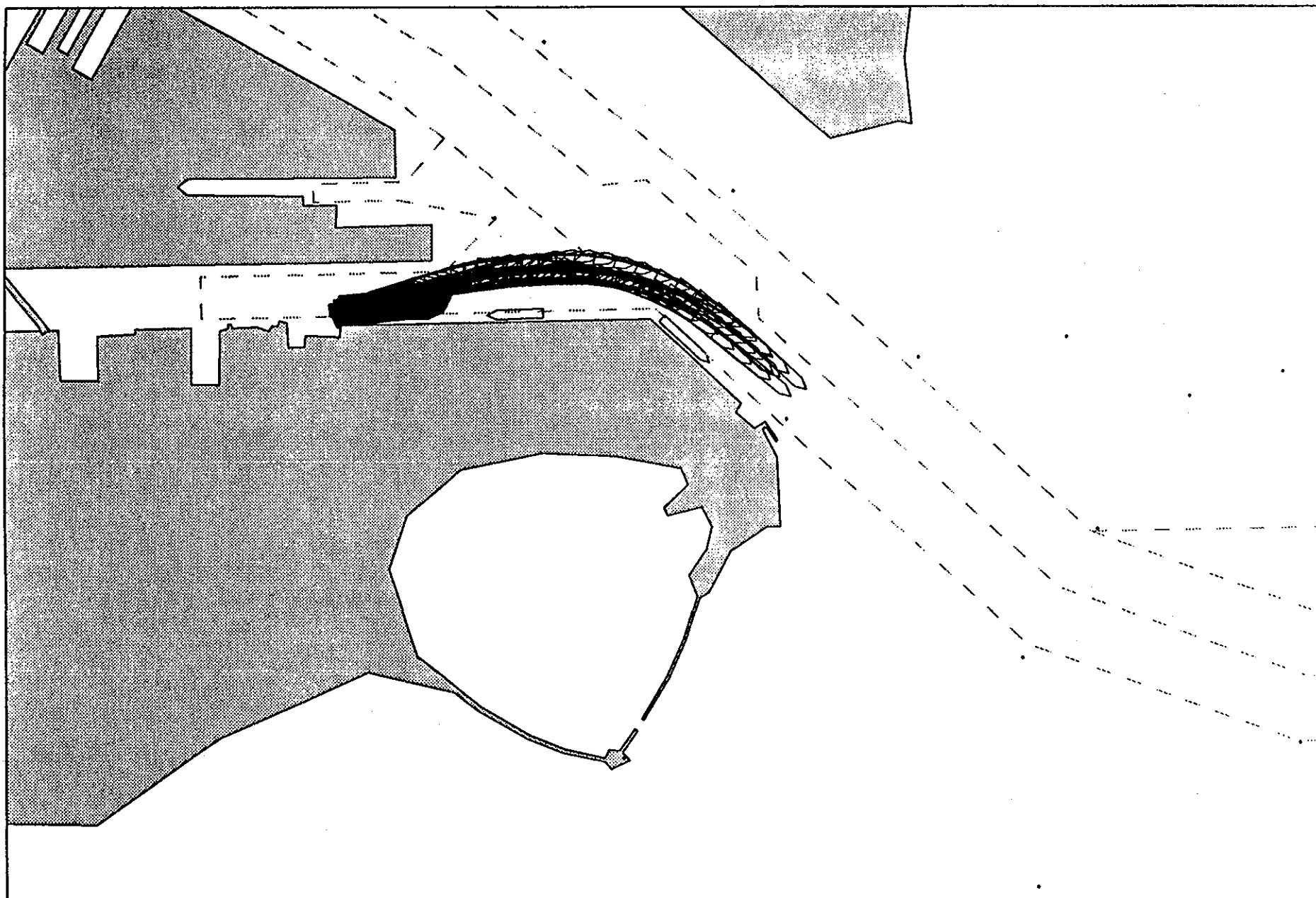


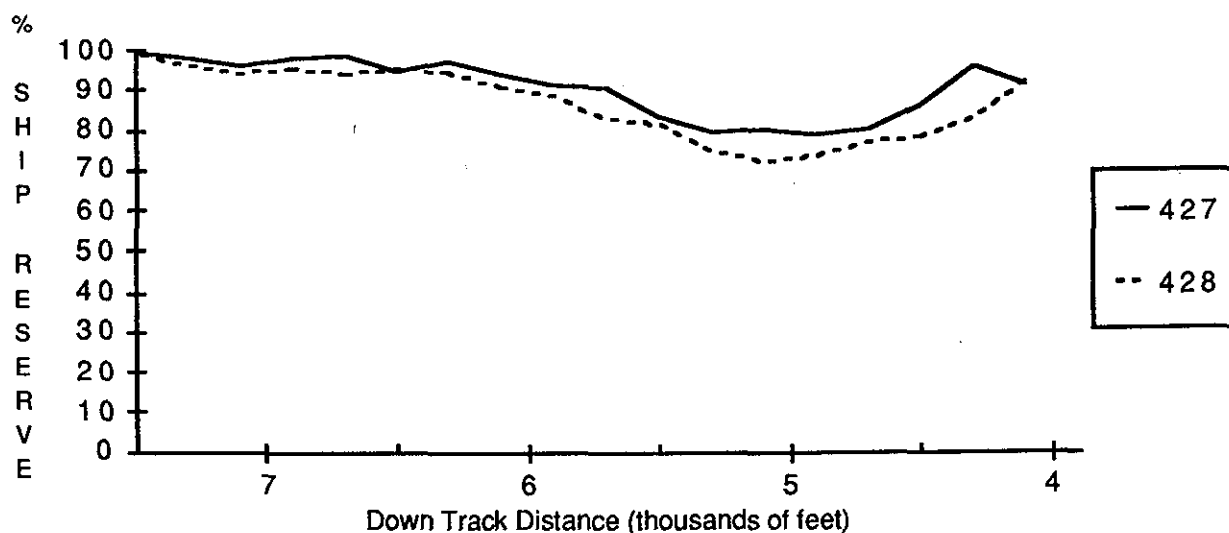
FIGURE 34 Composite Trackplot - Scenario 428 - Planned - Panamax

Discussion

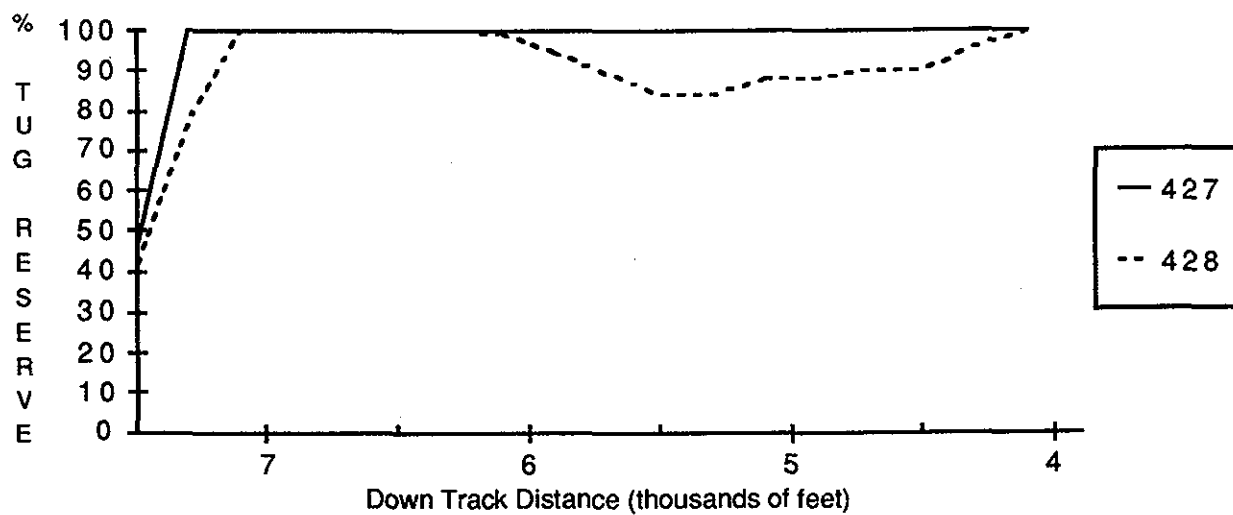
The pilots felt comfortable with the existing maneuver and gave safety ratings ranging from "Adequate" to "More than Adequate". One pilot did, however, cross the northern boundary of the Reserved Channel. With a tidal height of 2' above MLW, which is associated with the ebb tide modeled, this excursion could have resulted in a grounding. There were no recommendations by the pilots for additional tug support, and all the pilots successfully completed the turn on the 40' side of the Main Ship Channel.

Tests in the planned design yielded an average safety rating of "Adequate". Although the track plots showed good transits in the new configuration, some pilots expressed concerns about making the turn. This was due to the fact that the 35' MLW half of the Main Ship Channel was off limits since the tidal height was only 2' above MLW in the ebb scenario. One pilot commented that, to accomplish the turn without being set down on the ship at Castle Island, you have to put considerable headway on the ship, which would put the tugs in a dangerous situation if you needed them to work full ahead. Another pilot commented that, in the existing maneuver, there is the option of easing the rudder if you get too close to the moored vessel, but in the planned maneuver you do not have that option since you would end up in the 35' MLW half of the Main Ship Channel. The composite trackplot for the planned condition is shown in Figure 34.

The SRC and TRC, shown in Figures 35 and 36 respectively, indicate that the existing maneuver was accomplished solely under ships power once the vessel was pulled off the dock with the tug boats. In the planned scenario, however, a combination of ships power (more than in the existing scenario) and tug support was required to safely negotiate the turn into the Main Ship Channel.



**FIGURE 35 Ship Reserve Control - Scenarios 427/428
(mean values, all pilots)**



**FIGURE 36 Tug Reserve Control - Scenarios 427/428
(mean values, all pilots)**

SECTION 5 SUMMARY OF CONCLUSIONS

5.1 MYSTIC RIVER AND APPROACHES

It was demonstrated that the proposed widened Inner Confluence area provides adequate safety for the deeply loaded LNG. Based on some of the Pilot comments, however, there is a possibility that the loaded LNG may be safely maneuvered in the Inner Confluence Area without the proposed expansion. It is therefore recommended that this configuration be tested, which may lead to substantial savings in project costs.

The results indicate that the area in the South West quadrant of the Mystic River, which will not be maintained, reduces the safety of the LNG backing maneuver. Most of the test pilots recommended that this area be modified to provide more room. A slight tapering of this area is recommended.

Although it was shown that large tankers could access the Mystic River in the planned configuration, the margin of safety dropped to unacceptable levels due to a significant increase in the amount of tug assistance that was required to safely execute the maneuver. The results of the numerical analysis along with a strong Pilot endorsement support implementation of Plan 2.

The planned design provides adequate room for safely turning vessels in the Mystic River.

5.2 CHELSEA RIVER AND APPROACHES

The test vessel used in the lower reach of the Chelsea River resulted in marginal safety, even in the existing scenario, due to the vessel's overall dimensions and mass. It is anticipated that the deepening project will benefit ships with smaller overall dimensions and that vessels similar to the test vessel (50K DWT, 692' X 106, 42' draft) would represent the absolute largest vessel that could make the transit.

Two areas along the lower reach should be widened in conjunction with the deepening project to insure adequate safety for deeply loaded tankers.

In the planned design, the Chelsea Street Bridge transits were completed with only a marginal level of safety. The rest of the upper reach transit provided adequate safety. However, since all vessels would have to transit the bridge, the bridge and not the channel width is the limiting factor. The full benefit of the deepening project may, therefore, not be achievable due to the limiting factor of the Chelsea Street Bridge.

5.3 RESERVED CHANNEL AND APPROACHES

Although the proposed design for the Reserved Channel was successful in providing safe navigation for most of the scenarios tested, it failed to provide safe navigation for all operations. The 40' MLW notch area in the Main Ship Channel was not successful in providing a maneuvering area for all vessels.

There is strong evidence that a modified design may be acceptable if the Pilots employ a new maneuvering strategy, where they turn the ship in the 40' MLW area off the Massport Pier, instead of maneuvering in the area of the 40' MLW notch. This new design would require less dredging and lead to significant project savings. Using this new maneuvering strategy, three of four pilots were able to dock successfully, while none were able to dock successfully using the 40' MLW notch. More testing is recommended in this area due to the slightly higher than marginal safety rating that the pilots scored this maneuver. Further simulations with different notch configurations should be tested in order to fine tune the design and achieve a full test set of successful maneuvers. Possible

notch configurations that could be used to increase the safety of this maneuver are; shift the notch further upstream or increase the size and width of the notch into the 35' MLW channel. New configurations such as these should be tested prior to implementation in the real world.

Practice runs with pilots using the 40' MLW area off the Massport Pier should also be considered as an alternative to further dredging. There is overwhelming evidence that the 40' MLW area off the Massport Pier will provide maneuvering room for all vessels, tankers and container ships, and therefore, should be implemented.